AEDC-TR-89-2

C#3

# Surface Effects of Satellite Material Outgassing Products


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June 1989

Final Report for Period October 1, 1987 – February 1, 1989

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FOR THE COMMANDER

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION: Unclassified | 1b. RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY | 3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited. ~~Distribution authorized to U.S. Government agencies and their contractors; critical technology; June 1989. Other requests for~~ |
| 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S): AEDC-TR-89-2 | 5. MONITORING ORGANIZATION REPORT NUMBER(S) |
| 6a. NAME OF PERFORMING ORGANIZATION: Arnold Engineering Development Center — 6b. OFFICE SYMBOL (If applicable): DOT | 7a. NAME OF MONITORING ORGANIZATION |
| 6c. ADDRESS (City, State, and ZIP Code): Air Force Systems Command, Arnold Air Force Base, TN 37389-5000 | 7b. ADDRESS (City, State, and ZIP Code) |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Arnold Engineering Development Center — 8b. OFFICE SYMBOL (If applicable): DO | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER |
| 8c. ADDRESS (City, State, and ZIP Code): Air Force Systems Command, Arnold Air Force Base, TN 37389-5000 | 10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 65807F; PROJECT NO. DB72VW; TASK NO.; WORK UNIT ACCESSION NO. |

11. TITLE (Include Security Classification)
Surface Effects of Satellite Material Outgassing Products

12. PERSONAL AUTHOR(S)
Wood, B.E., Bertrand, W.T., and Kiech, E.L., Calspan Corporation/AEDC Operations, and

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Year, Month, Day) | 15. PAGE COUNT |
|---|---|---|---|
| Final | FROM 10/1/87 TO 2/1/89 | June 1989 | 82 |

16. SUPPLEMENTARY NOTATION
Available in Defense Technical Information Center (DTIC).

| 17. COSATI CODES FIELD | GROUP | SUB-GROUP | 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) |
|---|---|---|---|
| 20 | 06 | | contamination; optical properties; cryogenics |
| 22 | 02 | | refractive indices; outgassing; satellite materials |

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Optical property measurements of condensed contaminant films on cryogenically cooled substrates were completed for 18 additional materials to those reported in AEDC-TR-87-8, "Surface Effects of Satellite Outgassing Products." The materials studied were either being considered for use in space or in ground test chambers at Arnold Engineering Development Center (AEDC). Infrared spectral transmittance measurements were made for thin films of contaminant deposited on a 77 K germanium window under vacuum conditions ($10^{-6}$ torr). Material temperatures were controlled at 125°C for 24 hr to provide the outgassing source. The objective of this report is to present the refractive (n) and absorptive (k) indices of the condensed outgassing products of satellite materials which have been determined from the experimental measurements of the infrared transmittance spectra.

| | |
|---|---|
| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS | 21. ABSTRACT SECURITY CLASSIFICATION: Unclassified |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL: Mr. Carlton L. Garner | 22b. TELEPHONE (Include Area Code): (615) 454-7813 — 22c. OFFICE SYMBOL: DOCS |

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

3. DISTRIBUTION/AVAILABILITY OF REPORT. Concluded.

this document shall be referred to WRDC/MLBT, Wright-Patterson Air Force Base, OH 45433.

12. PERSONAL AUTHORS. Concluded.

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## PREFACE

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC) under Program Element 62102F. The results were obtained by Calspan Corporation, AEDC Operations, AEDC operating contractor for Aerospace Flight Dynamics testing at AEDC, AFSC, Arnold Air Force Base, Tennessee, under AEDC Project No. DB72VW (V32K-CT). The project was sponsored by the Wright Research and Development Center (WRDC), Wright-Patterson AFB, Ohio. The WRDC Project Manager was Capt. Pat Falco, and the AEDC Project Managers were Capt. Dale Holt and Capt. Seth Shepherd. This report documents research performed as an extension of work documented earlier in AEDC-TR-87-8, "Surface Effects of Satellite Outgassing Products." The authors would like to express their appreciation to Bill Hobbs and Winfred Johnson for their help with the chamber assembly, operation, and instrumentation. This report was submitted for publication on April 19, 1989.

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# 1.0 INTRODUCTION

As satellite applications become more sophisticated and their lifetimes are extended, the roles of contamination prediction and control become increasingly important. Contamination can end a mission because of cryogenically cooled optical systems becoming coated or thermal control surfaces becoming contaminated, thereby increasing the solar absorptance and causing the spacecraft to overheat. These are two of the most important ways contamination can adversely affect the mission.

A spacecraft designer must predict effects of contamination with a very limited amount of data. Previously, the ASTM 595 has been the industry standard for screening materials for their outgassing properties. The total mass loss (TML) and the collected volatile condensable material (CVCM) are used as guides. From the ASTM 595 criteria, a material, to be space rated, must have a TML of less than 1 percent and a CVCM of less than 0.1 percent. These parameters are determined by heating a sample to 125°C for 24 hr under vacuum. The TML is found from the measurements of the sample weight before and after heating. The CVCM is determined by weighing a 25°C collector surface which was positioned above the heated sample before and after the 24-hr heating cycle. Neither the time history nor the identification of outgassed species is available from the ASTM 595 test.

The Wright Research and Development Center (WRDC) is pursuing a plan to determine the outgassing properties of materials and the effects of condensed gases on critical surfaces such as thermal control and cryogenically cooled optical components. A WRDC-sponsored improved test method for determining material outgassing characteristics has been developed by Lockheed (Ref. 1). This method utilizes quartz crystal microbalances (QCMs) maintained at various temperatures between room temperature and 77 K to measure the mass loss by outgassing and the time history of each outgassed species. This test method can be used to indicate how much of a given satellite material may be lost in space by outgassing, but it cannot determine what effect the outgassed material will have on an optical or thermal radiative surface. The surface effects of these products are being studied at the Arnold Engineering Development Center (AEDC) under another program sponsored by WRDC.

The objectives of the WRDC program at AEDC are to establish a centralized Air Force surface effects facility for determining optical properties of satellite material outgassing products; determine refractive (n) and absorptive (k) indices for contaminant films condensed on cryogenic surfaces and establish a moderate data base for several satellite material categories such as paints, adhesives, films, composites, etc.; and provide computational-analytical thin-film programs for calculating contaminant effects on the transmittance/reflectance of cryogenically cooled optical components using derived contaminant n's and k's. The establishment of SDI has intensified the interest in determining effects of cryogenic contaminants. This is attributable to the use of cryogenic optics and sensors in many of the SDI systems.

The experimental investigations of cryogenically condensed contaminant films were carried out in the AEDC 2- by 3-ft Chamber. The materials were heated to 125°C under vacuum and the outgassed products were frozen as thin films on a 77 K germanium window. A scanning Michelson interferometer was used to measure the infrared transmittance over the 4,000 - 450 $cm^{-1}$ wavenumber range. From the recorded infrared transmittance data, the refractive and absorptive indices of the contaminant films were determined using a computational program (TRNLIN) which was based on a thin-film interference model. These n and k values can then be used with another program, CALCRT, developed at AEDC to calculate the transmittance or reflectance of other optical components contaminated with the outgassing products of the same satellite material as a function of contaminant film thickness, wavenumber, and incidence angle.

Infrared transmittance of contaminants condensed from seven satellite materials and the determined optical properties were previously reported in an AEDC publication (Ref. 2). The materials studied in Ref. 2 include Kapton® film, S13G/LO thermal control paint, and the adhesives RTV 732 Silastic, DC6-1104, DC93500, RTV566, and RTV560. In this report infrared spectra and optical properties of contaminant gases condensed on a 77 K germanium window are presented for additional paints, adhesives, films, composites, and lubricants. To date, 27 materials have been investigated, with infrared refractive and absorptive indices determined for 16 of those. The outgassing levels of the remaining materials were too low and resulted in film thicknesses too thin for determining the n's and k's using thin-film interference techiques. Outgassed contaminant species were determined from the infrared absorption band locations. The material total mass loss (TML) values were also obtained for each material. Contaminant film densities and refractive indices at the He-Ne laser wavelength (0.6328 μm) are also reported. Tabulated n,k data for the 16 materials investigated will eventually be included in a WRDC data base. The data and the CALCRT program are currently available on request to the authors.

## 2.0 EXPERIMENTAL TEST APPARATUS

### 2.1 CRYOGENIC CONTAMINATION CHAMBER

Infrared transmittance measurements were made of satellite material outgassing contamination products on cryogenic surfaces in the AEDC 2- by 3-ft Chamber (Figs. 1 and 2). The pumping system consisted of a turbomolecular pump with a mechanical forepump and a liquid nitrogen ($LN_2$)-cooled chamber liner. The turbo pump and the cryopanels were necessary to provide a near contaminant-free vacuum. With this pumping system a vacuum in the mid-$10^{-7}$ torr range could be routinely achieved. Thermocouple and ion gauges were used to monitor the chamber pressure. An effusion cell heated the materials to 125°C and provided the source of contamination.

The test surface was a germanium window mounted in the center of the chamber. It was cooled to near 77 K with a constant flow of $LN_2$. The germanium window temperature was monitored by platinum resistors embedded in the surrounding housing. The thin-film interference model on which the optical property determinations were based required that only the front surface be coated by the contaminant material. Therefore, special precautions were taken to ensure that nothing deposited on the rear surface. Two $LN_2$-cooled baffles were located behind the rear surface to scavenge any gases that otherwise would be incident on it. One was a rectangular flat plate located directly behind the germanium surface when it was in position for film deposition. The other was a hollow $LN_2$-cooled cylinder which shielded the rear surface when it was rotated into IR transmittance measurement position. The IR beam used in making the transmittance measurements passed through the center of the hollow tube.

### 2.1.1 Effusion Cell

The outgassing products for contaminating the sample surface were generated by an effusion cell. It had a cylindrical aluminum body 3.5 in. (8.89 cm) long with an internal bore diameter of 1.75 in. (4.45 cm). The material used to produce the outgassing flux was loaded into the closed end of the effusion cell, and the outgassing products exited through the open end. A Teflon® -coated heating element covered most of the outside surface of the cylinder. A temperature-controlled power supply was used to maintain the temperature of the cell at a constant value (usually 125°C). Cell temperatures were sensed by a thermocouple and controlled within $\pm 3°C$ of the set point. The effusion cell exit was positioned 2 in. (5.08 cm) from the germanium window and QCM. The centerline of the effusion cell was located midway between the centers of the germanium window and the QCM so that the deposition rates on the two were equal. This allowed film density measurements to be made.

The effusion cell was lined with disposable aluminum foil liners. The liners and aluminum foil sample boat were baked out at 125°C for 24 hr prior to each material test. This ensured that the deposited contaminants came from the material being investigated and not the peripheral components. New aluminum foil liners and boats were installed for each material investigated.

### 2.1.2 Germanium Window Deposition Surface

Germanium was picked for the deposition surface because it had good thermal conductance and a flat transmittance spectrum over the 700 - 4,000 $cm^{-1}$ (2.5 - 14 micrometers) wavenumber range. The window was 2.75 in. (6.99 cm) square and was 0.157 in. (4 mm) thick. Nominally, the transmittance of the window (at room temperature) was 47 - 48 percent over most of the wavenumber range. At 77 K the transmittance increased to about 49 percent in the flat portion of the spectrum.

The refractive index of germanium (Ref. 3) is given by

$$ng(\nu) = A + BL + CL^2 + D\nu^{-2} + E\nu^{-4} \quad (1)$$

where

$$\begin{aligned} \nu &= \text{wavenumber} \\ A &= 3.88 \\ B &= 0.391707 \\ C &= 0.163492 \\ D &= -0.000006 \\ E &= 0.000000053 \\ L &= (\nu^{-2} - 0.028)^{-1} \end{aligned}$$

### 2.1.3 Infrared Transmittance Measurement Equipment

A commercially made Michelson interferometer was utilized in making infrared transmittance measurements of the deposited contaminant film on the germanium window. A graphite radiation source was located inside the interferometer housing. The interferometrically modulated infrared beam was collimated and allowed to pass through a housing port. The exit beam was then passed through a KBr window on the chamber port, through the germanium test window, through another KBr window on the opposite side of the chamber, and finally to a box containing the detector optics and detector. The detector was a type C Hg-Cd-Te, which was sensitive to wavelengths from 4,000 - 450 $cm^{-1}$ (2 - 22 $\mu m$). Typically, 32 scans were co-added for both the sample and reference measurements with a resolution of 2 $cm^{-1}$. A reference measurement was made before each sample measurement. Data were initially stored on the system hard disk and later transferred to flexible disks.

### 2.1.4 QCM Configuration

For measuring the mass deposition, a quartz crystal microbalance (QCM) was used. The QCM had a mass sensitivity of $4.3 \times 10^{-9}$ gm/Hz • $cm^2$. The unit was made up of two crystals, the reference surface and the sensing surface. They had AT crystal cuts of 39° 40′ to minimize temperature effects at near $LN_2$ temperature. One of the crystals served as the sensing surface, whereas the other was not exposed to mass flux and was the reference. Any material that adhered to the sensing crystal altered the oscillator operating frequency. This change in frequency was proportional to the mass of material condensed on the crystal surface.

The QCM electronic controller was set up such that four outputs from the QCM were possible. They were mass, temperature, frequency, and mass rate. Knowing the rate and temperature at which mass accumulated (or evaporated) aided in interpreting the QCM data and identifying the species condensed or evaporated. The mass deposited on the sensing crystal was determined by recording the change in mass directly or by monitoring the frequency of the sensing crystal. The relation between the frequency change ($\Delta f$) and the deposited mass ($\Delta m$) can be expressed as (Ref. 4)

$$\Delta m = 1.4 \times 10^{-9} \, \Delta f \text{ gm/Hz} \tag{2}$$

or

$$\Delta m/S = 4.43 \times 10^{-9} \, \Delta f \text{ gm/cm}^2 * \text{Hz} \tag{3}$$

where $S$ = surface area of the sensing crystal electrode, 0.316 cm$^2$. If a density of 1.0 gm/cm$^3$ is assumed for the condensed film, then the change in film thickness ($\Delta t$) can be calculated from the frequency change ($\Delta f$) using the equation

$$\Delta t = 4.43 \times 10^{-9} \times \Delta f \tag{4}$$

where $\Delta t$ is given in centimeters and $\Delta f$ is given in Hertz.

QCM cooling to $LN_2$ temperature was accomplished by conduction because the balance was mounted directly to the $LN_2$-cooled housing holding the germanium window. Even so, the cooling rate was less than that of the germanium window. Temperature equilibrium was established for both the QCM and germanium window before the deposition of contaminants was begun.

## 3.0 EXPERIMENTAL TEST PROCEDURE

### 3.1 INTRODUCTION

The objective of this experiment was to study the surface effects of condensed outgassing products from satellite materials. Lockheed (Ref. 1) has established a test method for determining the expected mass loss of the same materials. It was desirable that both Lockheed and AEDC make measurements on similar sample materials under similar conditions. Therefore, some of the samples came from a common source provided and/or procured by Lockheed. In some instances this was not possible. A considerably larger quantity of material was required for the surface effects studies than for the outgassing measurements. Generally, 50 - 100 gm of material were required to get a sufficiently large contaminant thickness for determining the optical constants. Only 10 gm or less were required for most of the Lockheed outgassing studies.

The thin-film thickness measurement technique has been described previously (Refs. 5 and 6) and will only be reviewed here. To make accurate n,k measurements, the transmittance must be measured for carefully determined film thicknesses. The thin-film interference technique provided a method for calculating these discrete thicknesses. As a thin film forms on a reflecting (or transmitting) substrate, a reflected or transmitted beam of radiation will exhibit a sinusoidally varying signal. Using the thin-film interference equations, the maxima and minima locations can be used to calculate the thin-film thickness accurately from

$$t = m\lambda/2n(1 - \{\sin^2 \Theta / n^2\}^{0.5} \qquad (5)$$

where

| | | |
|---|---|---|
| t | = | film thickness, $\mu$m |
| $\lambda$ | = | wavelength, $\mu$m |
| n | = | real part of refractive index at wavelength $\lambda$ |
| $\Theta$ | = | incidence angle, deg |
| m | = | order of interference |

However, to make these calculations, the film refractive index, n, must be known for the incident wavelength. The He-Ne laser wavelength of 0.6328 $\mu$m was used. Since germanium does not transmit this wavelength, the technique was used in the reflective mode. Two He-Ne laser beams were incident at two angles (24.0 and 67.5 deg) and interference fringes were observed as the contaminant film was deposited. The refractive index at 0.6328 $\mu$m was determined from the interference patterns observed on a strip chart recorder trace for the two laser-solar cell outputs. This was done by fringe (interference maxima or minima) counting for each of the incidence angles and using the equation from Ref. 7

$$n = [\{\sin \Theta_1{}^2 - (m_1/m_2)^2 * \sin \Theta_2{}^2\} / (1 - (m_1/m_2)^2]^{0.5} \qquad (6)$$

where $\Theta_1$ and $\Theta_2$ were the two incidence angles, and $m_1$ and $m_2$ were the numbers of interference peaks counted for the angles $\Theta_1$ and $\Theta_2$, respectively.

Knowing the refractive index at 0.6328 $\mu$m, the film thicknesses at the interference maxima and minima peaks were easily calculated using Eq. (5). Either incidence angle could be used, but the smaller angle provided smaller thickness increments. For a sample thickness calculation, let $n = 1.4$, $\Theta_1 = 24$ deg, $\lambda = 0.6328$ $\mu$m, and $m = 1$ (for the first interference maxima). From Eq. (5) then, $t = 0.2474$ $\mu$m. Similarly, calculations for the first minima ($m = 1/2$) yield a film thickness of 0.1237 $\mu$m.

Film densities were determined from the calculated thickness, as discussed previously, and from the surface density ($gm/cm^2$) which was obtained from the QCM. This assumed that the surface density determined by the QCM was the same as that experienced by the germanium window. The density, d, ($gm/cm^3$) was determined from

$$d = (\Delta M/S)/t \tag{7}$$

where

$\Delta M$ is the change in mass detected by the QCM,
S is the surface area of the QCM element (0.316 $cm^2$), and
t is the film thickness in centimeters determined from Eq. (5)

The mass accumulated for each measured thickness was recorded and provided a means of determining film density. QCM frequency changes up to 100 KHz were assumed reliable. Densities calculated for frequencies above 100 KHz usually were somewhat higher (sometimes as much as 10 percent) than were observed for the smaller film thicknesses (QCM frequency changes of less than 100 KHz).

## 3.2 MATERIAL TEST SAMPLE REQUIREMENTS

### 3.2.1 Material Documentation and Preparation

At a joint meeting of government agencies and contractors, a list of most often used satellite materials that should be tested for contamination potential was compiled. This list is shown in Table 1 and was used as a guideline for determining the materials to be investigated.

Sample material time of preparation, cure time, mixture ratio, batch number, and preconditioning time were all carefully documented. In some instances, the cure time recommended was 7 days or longer. For some materials, insufficient contaminant mass (thickness) was deposited to allow enough transmittance measurements to determine reliable n,k values. In these cases, shorter cure times were used so that a greater contaminant flux could be generated. Generally, the longer the material cures, the lower its outgassing rate will be.

### 3.2.2 Material Sample Configuration and Pre-Conditioning

The adhesives and lubricants were contained in an aluminum foil boat which was 3 in. by 1.5 in. by 1.5 in. (7.62 cm by 3.81 cm by 3.81 cm). The empty aluminum foil boat was outgassed for 24 hr prior to filling with material. The paints were applied to aluminum foil strips (that had been previously outgassed at 125°C) of varying sizes. Initially, paints were applied to large foil strips, cured, rolled up, and inserted in the effusion cell. However, in some instances cracking and flaking of the paint became a problem. Therefore, smaller foil strips were used which could be directly placed in the effusion cell without any shaping required. The films and composites were placed in the effusion cell in the "as-received" condition. All materials were pre-conditioned by placing them in a 50-percent (±5 percent) relative humidity (R.H.) cell for 24 hr prior to installation in the chamber.

### 3.3 CRYOGENIC CONTAMINATION CHAMBER TEST PROCEDURES

After the test material had been pre-conditioned, the boat containing the sample material was inserted in the effusion cell and installed in the 2- by 3-ft Chamber. He-Ne laser alignment checks were carried out to ensure that the laser beams reflected from the germanium window were incident on the solar cell detectors. Also, the transmittance of the germanium window was inspected to ensure that no contaminant film had remained after cleaning. The housekeeping data program (See Ref. 2) was started for monitoring the QCM frequency, mass, temperature, and mass deposition rate. The effusion cell temperatures, the laser-solar cell outputs for the two incidence angles, and the germanium window temperatures were also monitored. The chamber was evacuated using a mechanical pump and a turbomolecular pump. Once the chamber pressure was reduced to the $10^{-5}$ torr level, the chamber liner was cooled to $LN_2$ temperature. After the liner reached $LN_2$ temperature, the $LN_2$ flow to the germanium window and QCM was started. The germanium window cooled down much quicker than the QCM because of its better thermal conductivity. When the chamber pressure reached the mid-to-high-$10^{-7}$-torr range, heating of the effusion cell was started. The effusion cell was thermostatically controlled to 125°C and the outgassed components were condensed on the germanium window and the QCM. The centers of the germanium window and the QCM were aligned equidistant from the effusion cell centerline so that the two surfaces would experience the same flux rate. The laser-solar cell outputs were documented versus time on a strip chart recorder. As the outgassed products condensed on the germanium window, the thin-film interference caused the laser-solar cell outputs to exhibit sinusoidally varying outputs. Deposition continued until the first interference minimum (quarter wavelength) occurred. The transmittance of the germanium window with the deposited film was then measured. This required rotating the germanium out of the deposition position into the transmittance measurement position. In making the transmittance measurement, a set of 32 scans was taken with the germanium rotated out of the infrared interferometer beam. This was the 100-percent, or reference, beam. The germanium window was then rotated into position so the interferometer beam was incident normal to it and another 32 scans were taken. The transmittance was determined by ratioing the Fourier transforms of the two sets of interferograms.

Once the transmittance measurements were completed, the germanium was rotated back into deposition position, and the film buildup and transmittance measurements continued. This procedure was repeated for as many thicknesses as could be obtained before the deposition rate decreased to a minimal value. For some materials, films up to 25 interference maxima thick were obtained. Transmittance measurements were made for as many thicknesses as possible to maximize the accuracy of the n,k calculations. The effusion cell heater was maintained at 125°C for the full 24 hr. This allowed a direct comparison of the TML values obtained in this report with the values given in Ref. 8 using the ASTM 595 method (125° C for 24 hr), and the values obtained with the Lockheed technique (QCM method, Ref. 1).

In some cases, transmittance measurements were made during warmup of the germanium window. This helped to determine the temperature at which the individual contaminant species were re-evaporated and to aid in their identification. Unfortunately, because the QCM and the germanium window warmup rates were different, the QCM could not be used to correlate mass loss with the germanium window and contaminant transmittance spectra. The spectral dependence on temperature, however, was obtained.

After the effusion cell had returned to room temperature, the 2- by 3-ft Chamber was pressurized to atmospheric pressure and the sample material was removed and weighed. The TML (percent) value was determined by dividing the mass lost attributable to outgassing (at 125°C under vacuum) by the original mass. The original mass was determined after removal from the 50-percent relative humidity chamber and prior to installation in the effusion cell.

The germanium window was observed after warmup and a transmittance spectrum was taken. For some materials there was a contaminant film left on the germanium. Transmittance measurements of the film usually showed evidence of hydrocarbons and silicones. The QCM also had a contaminant film left on it, evidenced by the fact that the frequency was, in some cases, 5,000 - 10,000 Hz higher than that observed prior to the beginning of the measurements. Both the germanium window and QCM were cleaned with alcohol or freon before the next material was studied.

## 4.0 RESULTS/DISCUSSION

The experimental results obtained for the outgassing products for the various materials heated to 125°C and condensed on the 77 K germanium window are presented. The transmittance data were used to determine the optical properties of the condensates. These refractive and absorptive indices will be presented and discussed in the next section. All of the materials studied to date are included in Table 2.

Contaminant specie identification was determined primarily through the use of the infrared absorption spectra. By far, the most prevalent specie was $H_2O$ which is characterized by a broad absorption band located between 3,100 and 3,500 $cm^{-1}$ with other weaker broad bands occurring at near 2,200, 1,700, and 800 $cm^{-1}$. Water is the most important of the outgassing species because it is the most prevalent and it has a relatively high absorption coefficient over most of the infrared wavenumber/wavelength region. $CO_2$ is easily identified by the very sharp absorption band located at 2,340 $cm^{-1}$ (4.3 $\mu$m). In cases where there is strong absorption by $CO_2$, the carbon and oxygen isotope bands may occur on either side of the 2,340 $cm^{-1}$ band. Hydrocarbons may have very complicated structure, but all show the characteristic C-H absorption band located in the vicinity of 3,000 - 3,100 $cm^{-1}$ ($\approx$3.4 $\mu$m). Usually, many other bands may be observed in the 800 - 1,800 $cm^{-1}$ range. The primary silicone band appears in the 1,000 and 1,100 $cm^{-1}$ range and, in most cases, associated combinations of the methyl-silicone bands are observed in the 800 - 1,800 $cm^{-1}$ interval.

## 4.1 PAINTS

### 4.1.1 Lockheed 0200 White Thermal Control Paint

Lockheed 0200 is a white thermal control coating developed by Lockheed for WRDC. The paint was brushed on five aluminum foil strips, allowed to dry for 24 hr, and placed in the 50-percent relative humidity environment for an additional 24 hr. The transmittance of the condensed outgassing products is shown in Fig. 4 for film thicknesses of 0.12, 1.00, and 5.24 $\mu$m. Water and $CO_2$ were the only major outgassed species observed. Although no total mass loss (TML) measurements were made, due to the paint flaking off, it was observed that the TML must have been high. Based on the deposition rates as determined by the QCM, the TML was estimated to be between 4 and 6 percent. The film density value was 1.03 gm/cc, which is higher than the density of ice, 0.92 gm/cc, which indicates the presence of some $CO_2$.

Similar measurements were made for Lockheed 0200 paint using 75°C as the effusion cell temperature instead of 125°C. It was found that the films deposited using the 75°C temperature had less $CO_2$ than corresponding film thicknesses obtained for the 125°C case. The refractive index and density (see Table 2) at 1.32 and 0.95 gm/cc, respectively, were lower than the corresponding values obtained at 125°C which were 1.33 and 1.03 gm/cc. These findings are consistent because $CO_2$ is known to have a higher density (1.67 gm/cc) than water (0.93 gm/cc), and a higher refractive index at 0.6328 $\mu$m (1.42) than water (1.32). Therefore, the higher outgassing temperature resulted in driving off a greater percentage of $CO_2$.

### 4.1.2 Lockheed 0100 White Thermal Control Paint

Lockheed 0100 is another white thermal control paint that was developed for WRDC. It was brushed on 10 aluminum foil strips and allowed to cure for 67 hr before measurements began. The total paint mass investigated was 8.8237 gm. Transmittances for film thicknesses of 0.14, 1.09, and 4.08 $\mu$m are shown in Fig. 5. Water was the only major contaminant specie as $CO_2$ shows up as a trace. The TML was found to be 5.95 percent. It was also observed that the paint, when brought back to atmospheric conditions, regained water vapor at a rapid rate. The contaminant film density was observed to be 0.82 gm/cc.

### 4.1.3 Lockheed 0300 Silver Flake Thermal Control Paint

Lockheed 0300 paint was a silver flake thermal control coating developed by Lockheed for WRDC. It was brushed on 25 small aluminum foil strips and allowed to cure for 7 days prior to the outgassing measurements. The total sample weight was 28.3688 gm. The transmittance spectra of the outgassing products on the 77 K germanium window are presented in Fig. 6 for film of 0.12-, 0.96-, and 2.77-$\mu$m thicknesses. $H_2O$, $CO_2$, and hydrocarbons were found to be the major contaminant species. The measured TML was 0.63 percent and the contaminant film density was 0.94 gm/cc.

### 4.1.4 Chemglaze Z306 Black Paint

Chemglaze Z306 is a black paint frequently used for component coatings on satellite systems. It is manufactured by Lord Corporation of Erie, PA. The paint was applied to nine aluminum foil strips with a total paint weight of 6.7162 gm. Transmittance spectra of the condensed outgassing products are shown in Fig. 7 for film thicknesses of 0.11, 0.91, and 1.82 $\mu$m. $H_2O$, $CO_2$, and hydrocarbons were the major contaminant species. The TML for this paint was 2.07 percent and the density of the condensed contaminant film was 1.03 gm/cc.

### 4.1.5 Chemglaze A276 White Paint

Chemglaze A276 white paint was also provided by the Lord Corporation of Erie, PA. (It was developed as a replacement for Chemglaze A237.) The paint was applied to four aluminum foil strips and the total paint weight was 14.9695 gm. Figure 8 shows the transmittance spectra for film thicknesses of 0.11, 0.90, and 4.92 $\mu$m and the spectra are quite complex. Again water, $CO_2$, and hydrocarbons are the dominant species. The TML was found to be quite high at 4.8 percent and the contaminant film density was 1.0 gm/cc.

## 4.2 ADHESIVES/POTTING COMPOUNDS

### 4.2.1 Solithane 113 Adhesive

Solithane 113, made by Morton-Thiokol, is a urethane prepolymer that is used primarily as a potting compound. It is a two-component system and was prepared by mixing 74 parts by weight of Solithane C113-300 curing agent with 100 parts of prepolymer. The combined material, 38.5315 gm, was cured for 7 days before the measurements began. Transmittance spectra for film thicknesses of 0.12 and 0.87 $\mu$m are shown in Fig. 9. Water, $CO_2$, and hydrocarbons can be readily identified in the figure. Other unknown products show strong absorption bands at approximately 2,300 and 1,625 cm$^{-1}$. The contaminant thickness obtained was not large enough to permit thickness calculations; thus, the density could not be calculated. Likewise the n's and k's could not be determined. The TML value was 0.20 percent.

### 4.2.2 Stycast 2850 Adhesive

Stycast 2850 is a potting compound made by Accrabond. It was prepared by mixing resin with 7 percent by weight of hardener. The total weight of material used in the measurements was 113.4790 gm, and it was cured for 43 hr. Figure 10 shows the infrared transmittance of contaminant films 0.12- and 0.36-$\mu$m thick. The primary contaminant specie was water with some $CO_2$ and a trace of hydrocarbons. Not enough outgassing material was collected to determine the refractive index at 0.6328 $\mu$m. Therefore, the film thickness as given in Table 2 is only approximate. The film density could not be determined. The TML was found to be 0.02 percent.

### 4.2.3 Epoxi-patch 6C Aluminum

The Epoxi-patch 6C aluminum potting compound was made by the Hysol Division and was prepared by mixing a 2.8 oz. tube of resin with 1.2 oz. of hardener. The mixture, weighing 89.6960 gm, was poured into an aluminum foil boat and allowed to cure for 24 hr. Figure 11 shows the transmittance of contaminant films 0.12- and 0.24-$\mu$m thick. The only species detectable were $H_2O$ and $CO_2$. The TML measured was 0.01 percent but again this was for the material in bulk. Not enough outgassed material was obtained to determine the refractive index at 0.6328 $\mu$m, so the thicknesses given in Fig. 11 are only approximate.

### 4.2.4 Crest 7450 Adhesive

Crest 7450 adhesive, manufactured by the Crest Company, was mixed in the ratio of 16 parts catalyst to 100 parts resin. It was allowed to cure at 75°F for 22 hr and then was heated to 300°F for 40 min. The strong $CO_2$ absorption band located at 2,340 $cm^{-1}$ (4.3 $\mu m$) was observed in the IR transmittance spectra as shown in Fig. 12 for film thicknesses of 0.13, 1.01, and 6.53 $\mu m$ thick. It was observed that for the 6.53-$\mu$m-thick film, the film is totally absorbing at 2,340 $cm^{-1}$. Considerable absorption is also seen in the water and hydrocarbon bands. The sample weight before the outgassing measurements was 93.0990 gm. The TML observed was 0.35 percent and the density of the condensed contaminant films was 0.94 gm/cc.

#### 4.2.5 Mocap Self-Fusing Tape

This self-fusing silicone tape is manufactured by Mocap and comes in thin strips. A small piece weighing 1.1217 gm was placed in the 50-percent R.H. environment for 24 hr prior to the measurements. The TML observed for the tape was 0.52 percent. Since the sample was so small, very little contamination was observed. Figure 13 shows the transmittance for films 0.12 and 0.18 $\mu m$ thick.These thicknesses are only approximate as the refractive index could not be determined for such a thin film. The contaminant film shows the silicone characteristic absorption bands between 800 and 1,400 $cm^{-1}$. No evidence of the presence of the $H_2O$ contaminant specie was observed.

### 4.3 FILMS

#### 4.3.1 Mylar Film

Several layers of 5- mil-thick Mylar® film were rolled up and placed in the effusion cell. The weight was 123.0593 gm. It was pre-conditioned at 50-percent R.H. for 24 hr prior to placement in the effusion cell. The TML was found to be 0.13 percent. The transmittance of the contaminant films is shown in Fig. 14 for thicknesses of 0.13, 0.91, and 1.05 $\mu m$. Both water and $CO_2$ contaminants were observed, with a slight trace of hydrocarbons with water being by far the most predominant. The film density was 1.07 gm/cc.

#### 4.3.2 FEP Teflon Film

One-mil Teflon film sheets with a total weight of 142.7436 gm were rolled up and placed in the effusion cell. Figure 15 shows the infrared transmittance of contaminant films approximately 0.12 and 0.24 $\mu m$ thick. The only identifiable contaminant specie present was $H_2O$. A TML value of 0.01 percent was observed.

### 4.4 COMPOSITES

The composite surfaces studied were provided by Martin-Marietta of Oak Ridge, TN, working in conjunction with the Materials Lab of WRDC. These materials were being investigated as possible structural materials for use as SDI space platforms. SDI materials are required to have low outgassing rates since cryogenically cooled optics and detectors are expected to be on board. These composites are made up of carbon fibers encased in some type of matrix.

### 4.4.1 PEEK/AS4 Composite

PEEK is an abbreviation for polyethyletherketone. The multifilament carbon fibers account for approximately 68 percent by weight of the composite. The material studied was composed of 31 pieces of varying rectangular sizes with a total weight of 82.9237 gm. Figure 16 shows the transmittance for contaminant film thicknesses of approximately 0.12 and 0.25 $\mu$m. The only outgassing specie seen is $H_2O$. The TML measured was 0.03 percent

### 4.4.2 J2/AS4 Composite

J2/AS4 composite is a polyimide copolymer produced by Dupont. The weight of 38 rectangular pieces was 110.7016 gm. The transmittance spectra for the condensed outgassing products are shown in Fig. 17 for film thicknesses of 0.13, 1.00, and 3.01 $\mu$m. As observed for the PEEK material, $H_2O$ is the only outgassed product. For this material the TML was found to be 0.24 percent. The film density was 0.85 gm/cc.

### 4.4.3 AS4/PPS Composite

AS4/PPS material is a polyphenylene sulphide. The sample material studied consisted of 31 rectangular pieces with a total weight of 93.1507 gm. Due to a problem encountered during the experiment, infrared transmittance data were not possible for contaminant films. However, the material was kept at 125°C for the full 24 hr so that the TML value could be obtained. The TML was found to be 0.03 percent, which is the same value that was observed for the PEEK material. From a study of the QCM data, it was determined that during warmup, the contaminant film evaporated between 160 and 170 K, which is where $H_2O$ films evaporate under a pressure of $10^{-6}$ torr. Therefore, qualitatively it can be assumed that most of the contaminant film was composed of $H_2O$.

### 4.4.4 EP30LI Composite

EP30LI composite (also known as AS4/3501-6) material consisted of 25 rectangular pieces that weighed 102.1996 gm before the studies began. Figure 18 shows the transmittance for contaminant films 0.13, 1.00, and 1.51 $\mu$m thick. The only identifiable contaminant specie is $H_2O$. The TML obtained for this material was 0.12 percent and the film density was 0.75 gm/cc.

#### 4.4.5 Graphite Epoxy

This graphite epoxy material (AS4/3501) was obtained directly from WRDC. The manufacturer and material components were not provided. There were ten rectangular pieces with a combined weight of 70.5290 gm. Figure 19 presents the transmittance spectra for film thicknesses of 0.12 and 1.00 $\mu$m. Again, the major outgassing component was $H_2O$ with a slight trace of $CO_2$ observed for the largest thickness. The TML measured was 0.23 percent, and film density was 1.08 gm/cc.

### 4.5 LUBRICANTS

#### 4.5.1 Braycote 600 Grease

The Braycote 600 grease was provided by the Bray Oil Company. The sample weighed 24.4514 gm (one tube) and was put into an aluminum foil boat which had been previously outgassed for 24 hr at 125°C. Figure 20 shows the infrared transmittance of contaminant films 0.12, and 0.24 $\mu$m thick. Water, hydrocarbons, and a slight trace of $CO_2$ were the contaminant species observed. The TML for this material was found to be 0.04 percent.

#### 4.5.2 Brayco 815Z Oil

Brayco 815Z oil was also provided by Bray Oil Company. The sample was a liquid and was poured into an aluminum foil boat. The weight of the oil was 23.4188 gm. This oil outgassed very little (TML = 0.02 percent) and as a result a contaminant layer of approximately 0.12-$\mu$m thickness was the largest obtained. The transmittance is shown in Fig. 21. Water and hydrocarbons make up the contaminant species observed. This material, again, would be an excellent choice for a spacecraft lubricant based on outgassing alone.

#### 4.5.3 Vac-Kote Oil

Vac-Kote oil was studied by pouring 25.6443 gm into an aluminum foil boat. When heated to 125°C, the material outgassing rate remained at a constant value for the entire 24 hr. This indicates that the products coming from the oil weren't really outgassing products but were simply the result of the oil evaporating. The TML value obtained after the 24 hr of heating under vacuum was 1.97 percent. Figure 22 presents the transmittance spectra and shows only the presence of hydrocarbons. No outgassing of the water specie was observed. The film density was 0.66 gm/cc.

## 5.0 OPTICAL PROPERTIES OF SATELLITE MATERIAL OUTGASSING PRODUCTS

Most contaminant problems encountered in space involve contaminant thicknesses of a few micrometers or less. Therefore, thin-film interference equations are generally used to predict contaminant effects on the reflectance or transmittance of an optical element. These calculations require knowledge of the contaminant film optical properties—the refractive and absorptive indices, n and k. They are components of the more general expression for the complex refractive index given by $n^* = n - ik$. To determine the complex refractive index of the thin solid contaminant films, an analytical model of film plus substrate transmittance has been developed at AEDC by Roux (Refs. 5, 6, 9, and 10). Most of the model follows the expressions given by Heavens in Ref. 11 for thin-film transmittance and reflectance. The model assumes the germanium window is a thick film (see Fig. 23) and there is no phase coherence between multiple internally reflected rays. All interference occurs within the thin contaminant film. An expression is derived for the normal transmittance of a thin film on a non-absorbing substrate and its derivation is shown by Roux in Refs. 5 and 9. The resulting expression for the transmittance is summarized as

$$T = T(n, k, \Theta, N_g, \nu, d) \tag{7}$$

which is a very long and cumbersome expression where n and k represent the film refractive and absorptive indices, respectively. $\Theta$ is the incidence angle, $N_g$ is the real part of the substrate refractive index, $\nu$ is the wavenumber, and d is the film thickness. Expressions for the partially absorbing substrate cases are also available but were not used in this study.

The optical constants of the contaminant films were determined using the experimentally measured transmittance values over the 4,000 - 700 $cm^{-1}$ wavenumber range and for as many film thicknesses as possible. Generally at least ten film thicknesses (and preferably more) were required to determine n and k. The transmittance values for all film thicknesses were input into the computer program TRNLIN which uses the analytical thin-film interference transmittance model and a nonlinear least-squares convergence routine for determining n and k. In some instances, the program did not converge upon a unique value of n. This usually occurred in regions of strong absorption or low wavenumber, or where it was only possible to form a few thicknesses of contaminant. The n value appears to be primarily defined by the period of the transmittance versus thickness curve at each wavenumber. At small thicknesses, high absorption, or low wavenumbers, the transmittance versus thickness (for each wavenumber) curve is not well defined, i.e., the period of the interference as a function of thickness is not well defined. The k value, which is primarily defined by the magnitude of the transmittance, was well defined for the entire spectral range (700 to 4,000 $cm^{-1}$). Therefore, for cases where the n values were not uniquely defined, the k values were used with the Subtractive Kramers-Kronig relationship to compute n.

The Subtractive Kramers-Kronig expression is given by

$$n(\nu) = n(\nu_m) + (2/\pi)\, P \int_0^\infty \frac{k(\nu')\nu' - k(\nu)\nu}{(\nu')^2 - (\nu)^2} - \frac{k(\nu')\nu' - k(\nu_m)\nu_m}{(\nu')^2 - (\nu_m)^2}\, d\nu' \qquad (8)$$

where $\nu_m$ is a reference frequency and P is the Cauchy principal integral value. The $k(\nu')$ values used in Eq. (8) were those determined using TRNLIN. These new n values were then used in the analytical model (along with the k values) to see if good agreement with the transmittance data was obtained. Generally, the Subtractive Kramers-Kronig n values yielded good agreement (within 1 percent) when the analytical model results and actual transmittance data were compared. The n values, derived using TRNLIN, were usually larger in areas of strong absorption than the Kramers-Kronig values. This may be due to the Subtractive Kramers-Kronig integration being carried out over the wavenumber range (700 - 4,000 $cm^{-1}$) instead of from zero to + infinity as specified in the integration limits of Eq. (8).

The refractive and absorptive indices determined from the transmittance data are shown in Figs. 24 - 34 for the materials described previously. The refractive indices are shown at the top of the figure with the absorptive indices directly below.

The transmittance experimental data were taken using 2 $cm^{-1}$ resolution. The n's and k's were determined at every 2 $cm^{-1}$ in the range from 700 to 4,000 $cm^{-1}$. An example of the tabulated n,k data that have been obtained for each of the materials mentioned previously is given in Table 3. Results presented in Table 3 are for Chemglaze Z306. Similar tables are available for each of the other materials investigated.

The standard deviations for each wavenumber were calculated as part of the TRNLIN program. They generally varied with wavenumber but, for the most part, were on the order of 0.02 for the refractive index and 0.005 for the absorptive index. The accuracy of the experimental measurements for determining the n's and k's is estimated to be within 3 percent. The real test was to determine how the transmittance values, calculated using the derived n's and k's, agreed with the experimentally determined values. This will be discussed in the following section.

## 6.0 TRANSMITTANCE AND REFLECTANCE CALCULATIONS USING CALCRT

To realize the maximum utility of the data (n's and k's) generated from the experimental and analytical studies, it was necessary to develop another computer program, CALCRT (calculations of reflectance and transmittance). This program was written for AEDC by Dr. Kent Palmer of Westminster College in Fulton, MO. CALCRT, written in FORTRAN IV, calculates the reflectances and transmittances of a radiation beam that strikes a film and substrate system which has planar interfaces. The interfaces are, ideally, infinite in extent. The film and substrate are sandwiched between semi-infinite vacuums, so that the refractive indices on each side of the film-substrate are identically equal to one.

The user must supply the substrate optical constants and thicknesses, the contaminant optical constants and thicknesses, and the radiation beam incidence angle. Transmittance or reflectance can be calculated as functions of contaminant film thickness or wavenumber.

## 6.1 CALCRT TRANSMITTANCE CALCULATIONS

To show how CALCRT can be used, examples of transmittance versus wavenumber and transmittance versus thickness were calculated for condensed outgassing products of Chemglaze Z306 paint. The Chemglaze Z306 n's and k's used are those presented in Table 3. Figures 35 - 37 show plots of transmittance versus wavenumber for films 0.23, 0.91, and 1.82 $\mu$m thick, respectively. Both measured and predicted curves are shown for comparison. As seen in the figures, there is excellent agreement between the predicted and experimentally measured values.

CALCRT can also be used to calculate the transmittance dependence on film thickness; examples are shown in Figs. 38 - 40. The curves presented in Figs. 38 - 40 are for 1,250, 2,000, and 3,250 cm$^{-1}$, respectively and represent effects of the outgassing products of Chemglaze Z306 paint on the window. The solid curves in each of the three figures represent the analytical results calculated using the TRNLIN-derived n's and k's. The data points are the actual experimental values. As can be seen in the figures, the predicted and experimental results agree quite well; standard deviations for these curves are 0.005, 0.015, and 0.031, respectively. The contaminant film n and k values used in the calculations at each wavenumber are given in the figures.

## 6.2 CALCRT REFLECTANCE CALCULATIONS FOR PURE WATER FILMS

Many of the outgassing problems encountered by satellites having cryogenic optics are directly linked to the outgassing of water vapor from the materials. Therefore, CALCRT was used to calculate the effects of condensed water films on a 77 K mirror surface near the $CO_2$ laser wavelength of 10.6 $\mu$m (943 cm$^{-1}$) and also at 10.0 $\mu$m (1,000 cm$^{-1}$). The n's and k's for the pure $H_2O$ films were taken from Wood and Roux, Ref. 5. (Note: n,k values were not available at exactly 943 cm$^{-1}$, so values at 940 cm$^{-1}$ were used.) The n and k values at 940 cm$^{-1}$ were 1.067 and 0.1499, respectively, whereas for 1,000 cm$^{-1}$, n was found to be 1.171 and k was 0.0374. The reflectance for the two wavelengths is shown in Fig. 41. For these calculations, the substrate is assumed to be a specular metal surface, such as a gold mirror, with a complex refractive index of $n^* = 1.8 + 18.0i$ and independent of wavelength/wavenumber. This yields a bare surface reflectance of 97.8 percent for all wavelengths/wavenumbers. The thin-film interference effects are vividly displayed for both wavenumbers. These curves give a good indication of how a mirror's reflectance can be degraded due to the deposition of a thin $H_2O$ contaminant film and show why cryogenic optical systems must be carefully shielded from contamination by water.

## 7.0 SUMMARY

Optical property measurements of condensed contaminant films on cryogenically cooled substrates were completed for 20 additional materials to those reported in Ref. 2. The materials studied were those used on space satellites or in ground test chambers at the Arnold Engineering Development Center (AEDC). Infrared spectral transmittance measurements were made for thin films of contaminant deposited on a 77 K germanium window under vacuum conditions ($10^{-6}$ torr). Material temperatures were controlled at 125°C for 24 hr to provide the outgassing source. Refractive and absorptive indices (n,k) were determined from the spectral transmittance data. These optical properties can be used to calculate the surface effects of contaminants from these materials on other optical surfaces.

All of the infrared transmittance measurements of contaminants outgassed from spacecraft and ground test materials studied to date are documented. The infrared spectra were obtained using a Fourier transform spectrometer for wavenumbers between 4,000 and 500 $cm^{-1}$ (2.5 - 20 $\mu$m). Outgassed contaminant species can be determined from the infrared absorption band locations. The material total mass loss (TML) values were also obtained for each material. Contaminant film densities and refractive indices at the He-Ne laser wavelength (0.6328 $\mu$m) are also reported. Tabulated n,k data for 16 of the materials investigated will eventually be included in an WRDC data base. The data and the CALCRT program are currently available on request to the authors.

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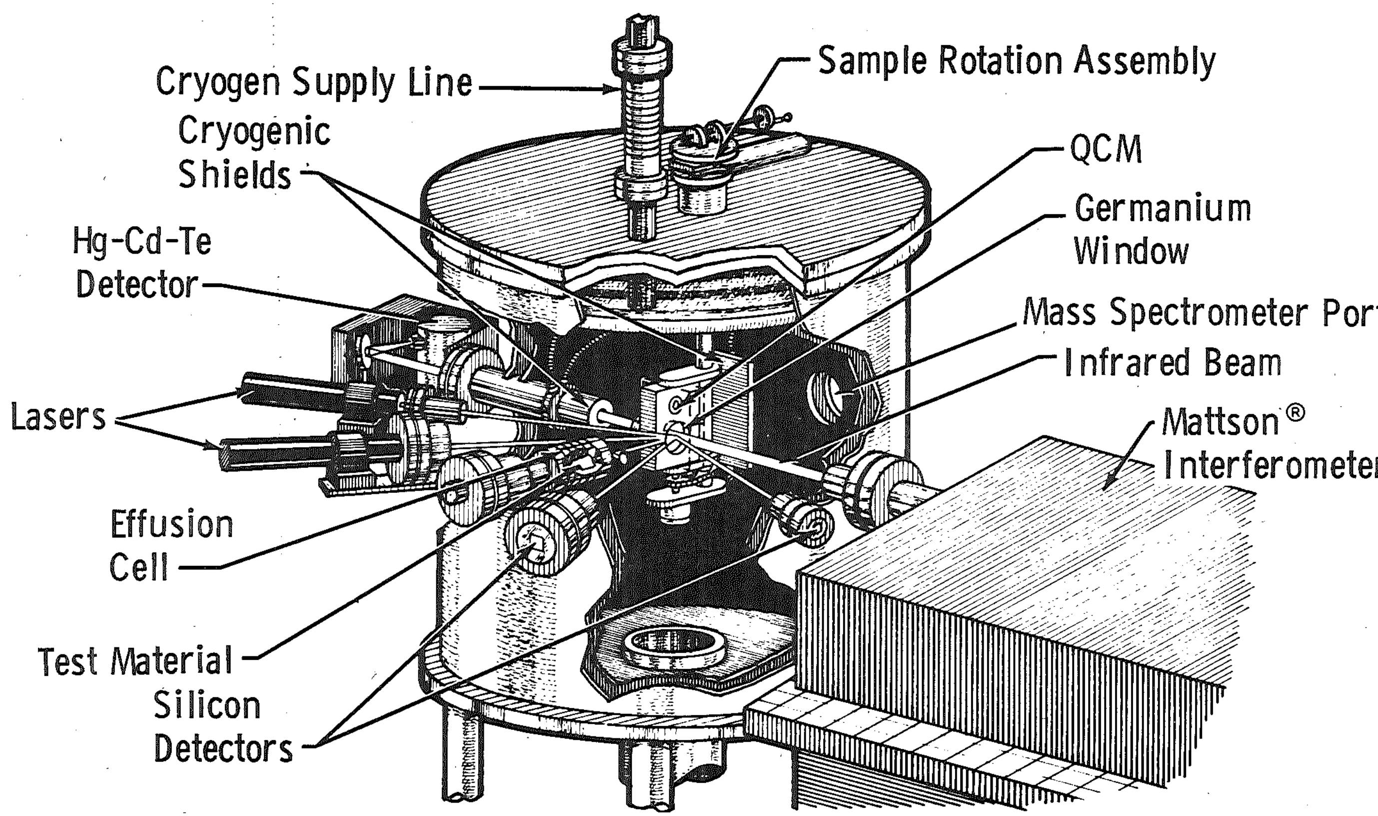



Figure 1. Schematic of the 2-by 3-ft Cryogenic Optics Degradation Chamber.

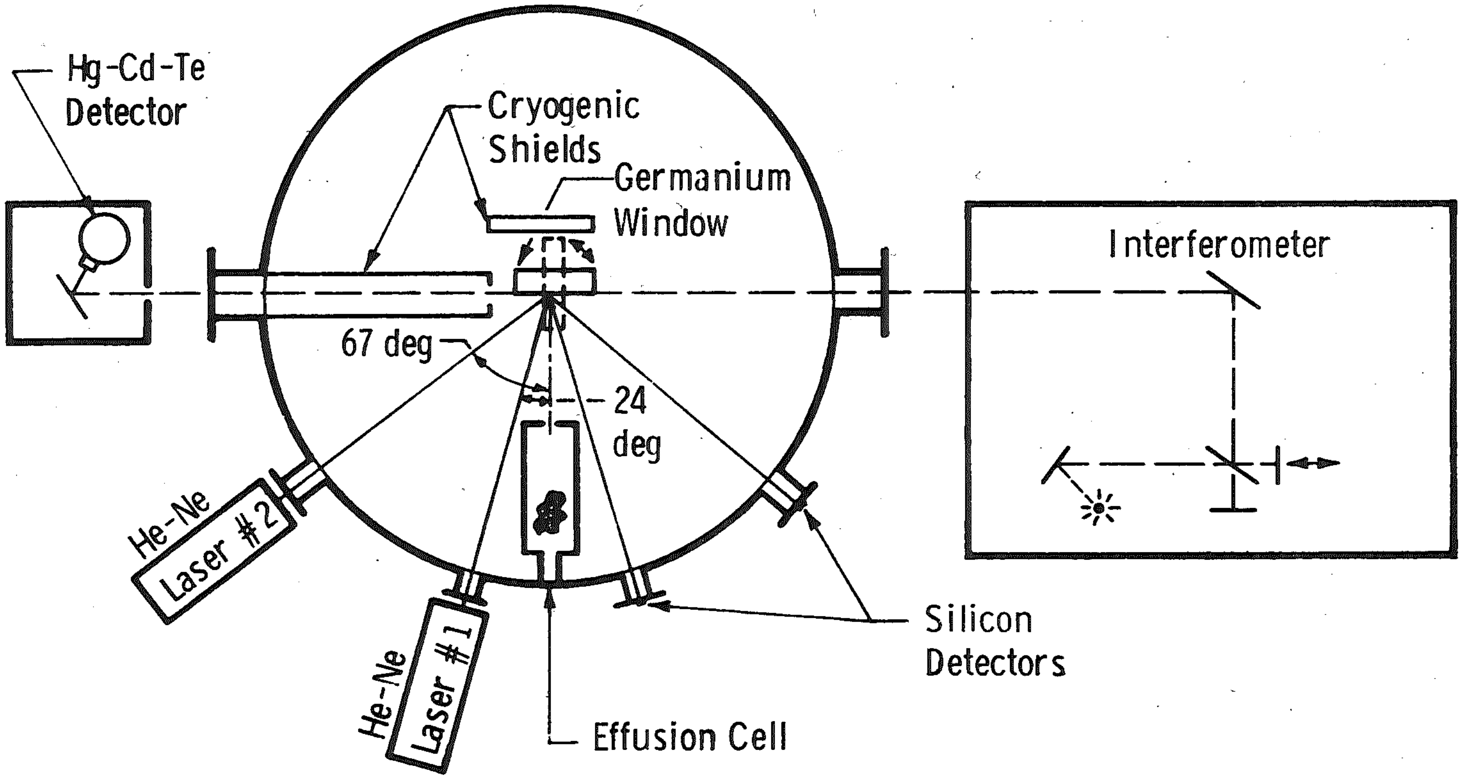



Figure 2. Schematic of 2- by 3-ft chamber components.

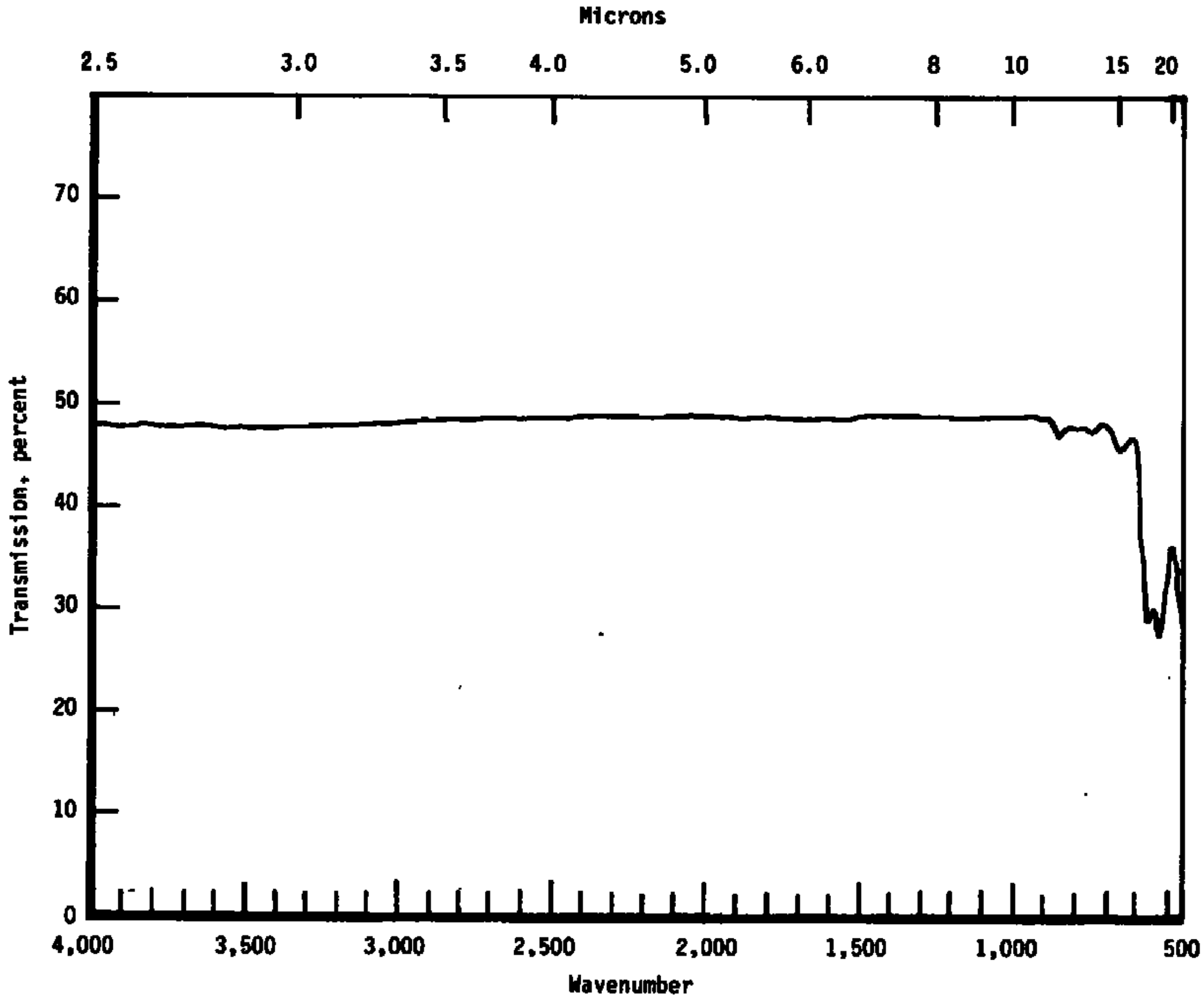



**Figure 3. Transmittance of a bare germanium window at 77 K.**

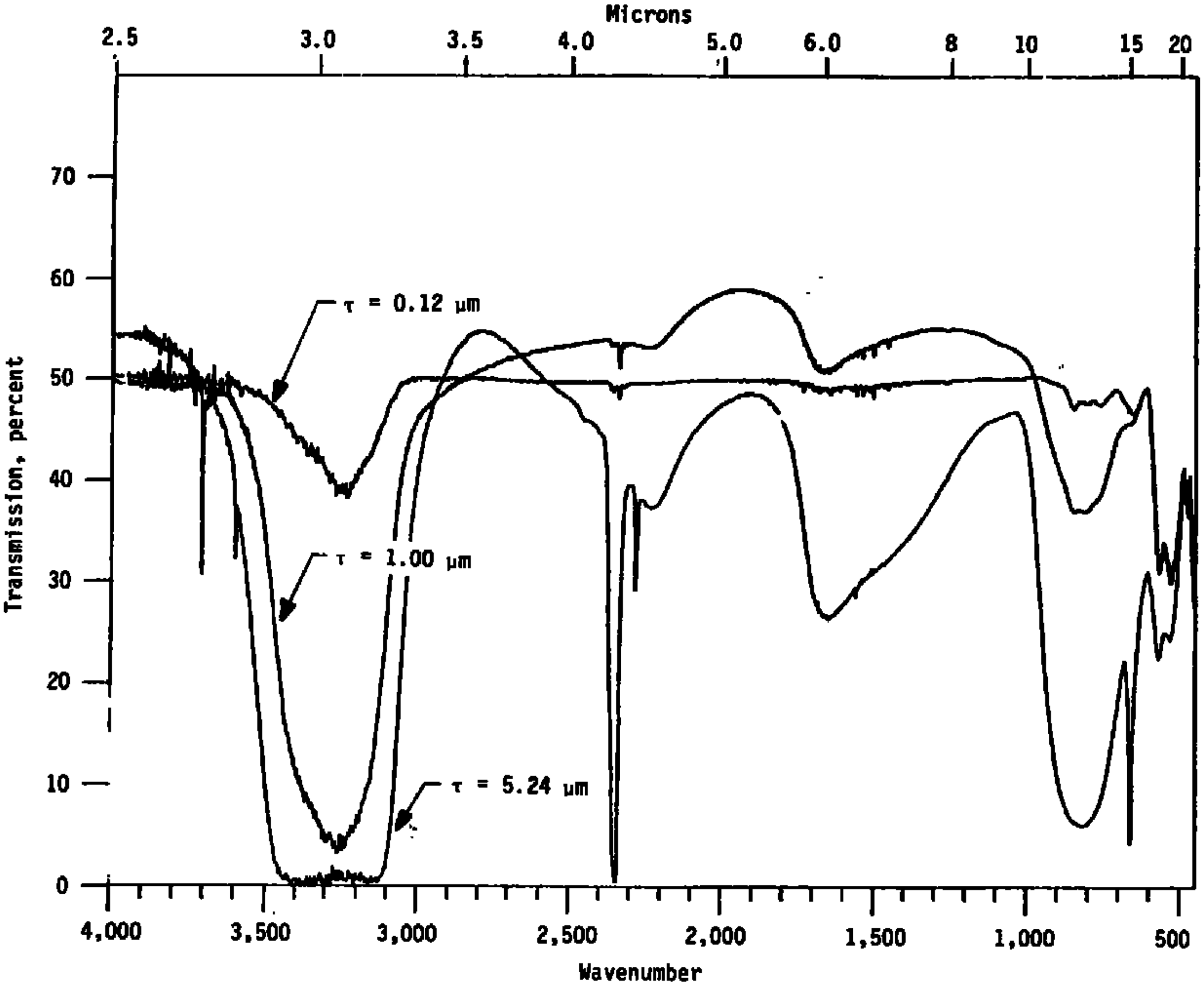



**Figure 4. Transmittance of Lockheed 0200 (white) paint outgassing contaminants on 77 K germanium for film thicknesses of 0.12, 1.00, and 5.24 μm.**

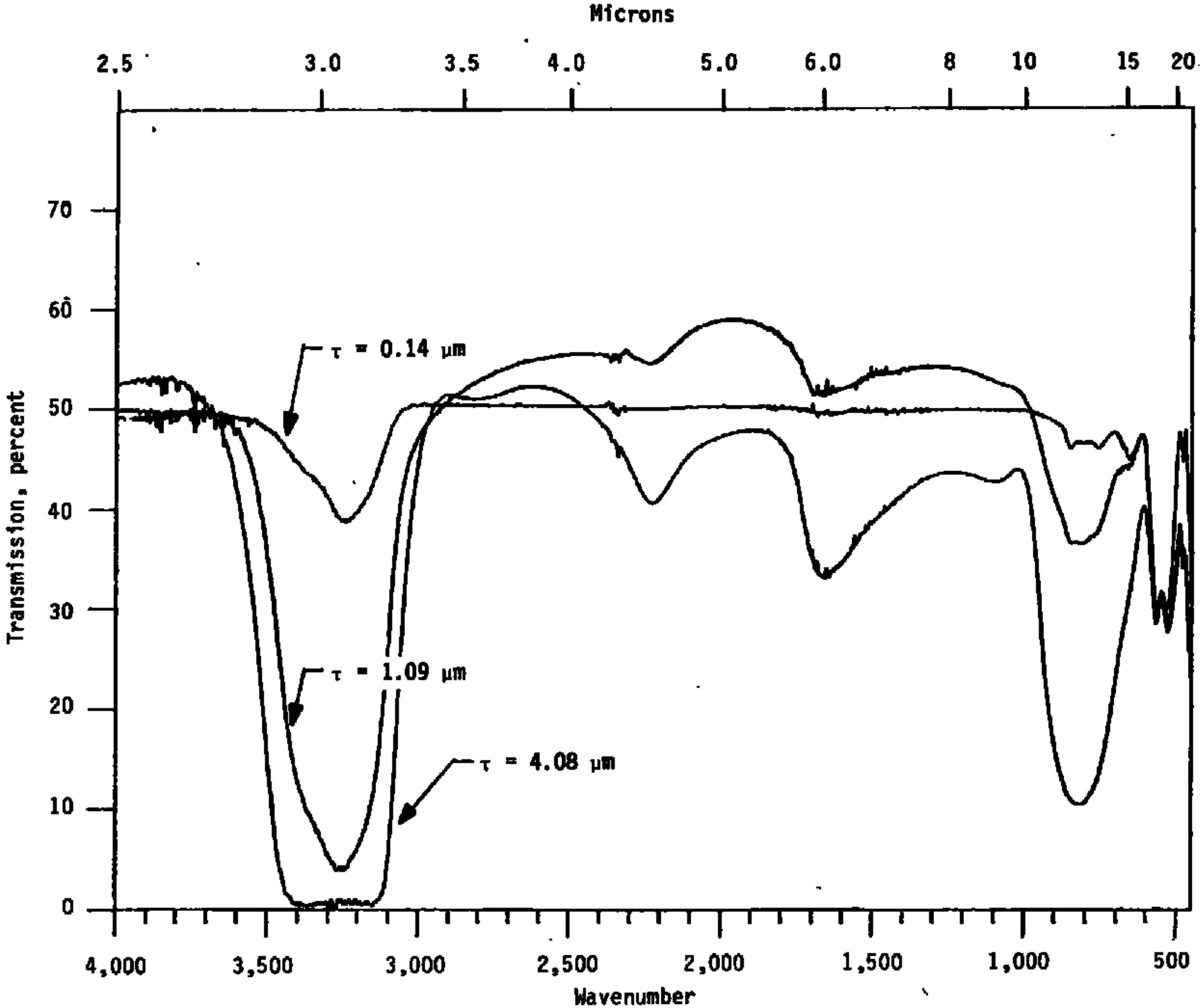



**Figure 5. Transmittance of Lockheed 0100 (white) paint outgassing contaminants on 77 K germanium for film thicknesses of 0.14, 1.09, and 4.08 $\mu$m.**

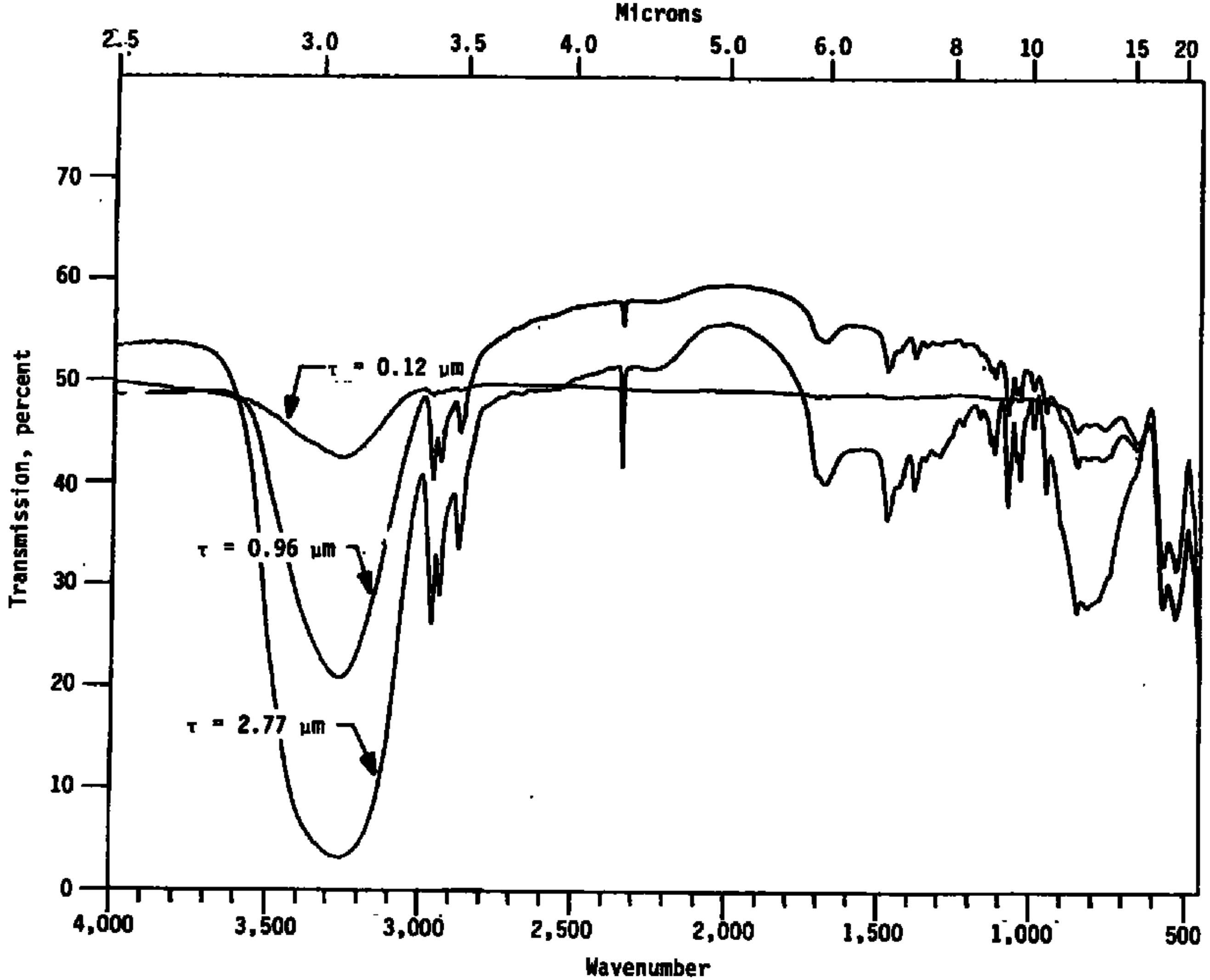



**Figure 6. Transmittance of Lockheed 0300 (silver flake) paint outgassing contaminants on 77 K germanium for film thicknesses of 0.12, 0.96, and 2.77 μm.**

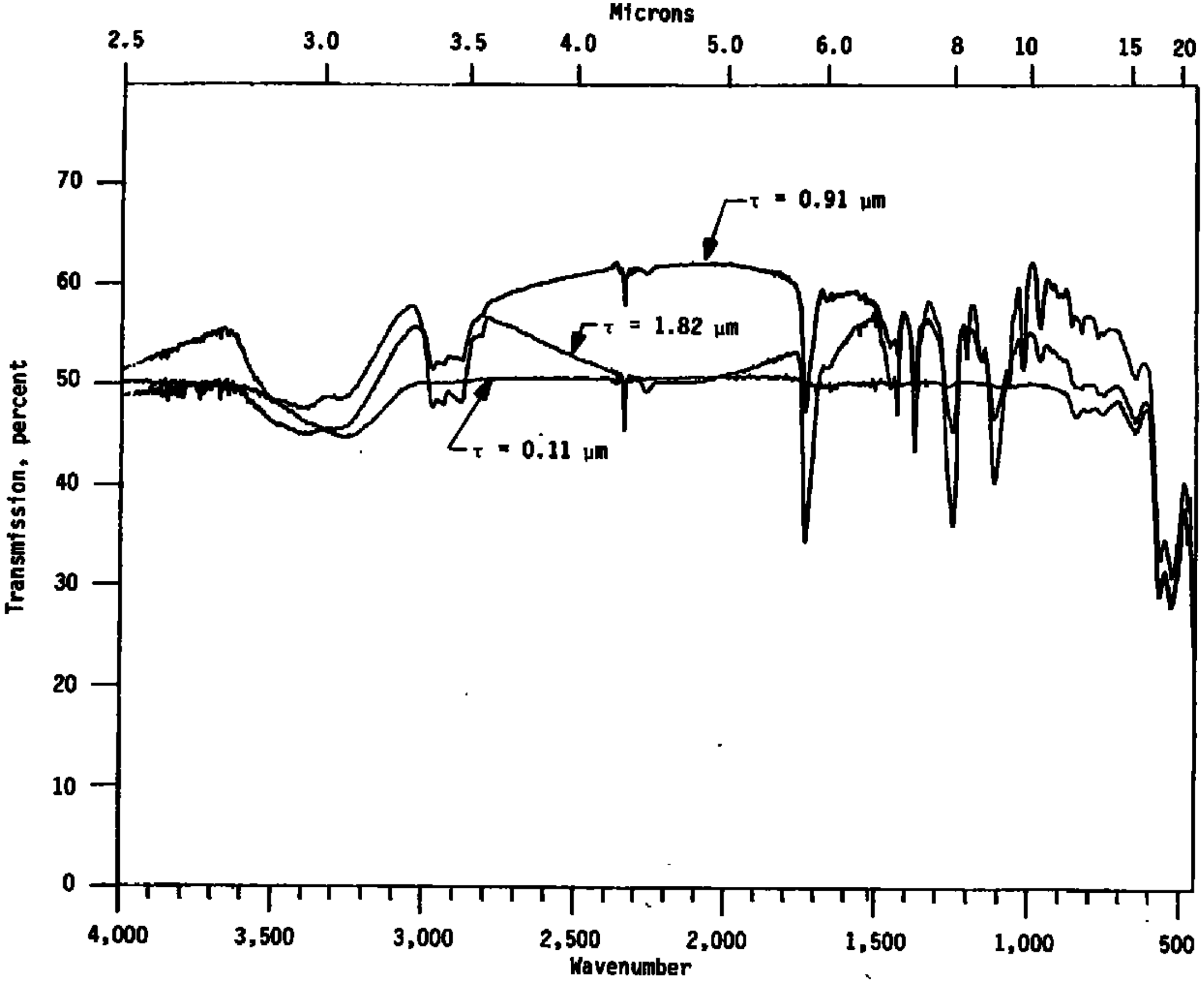



**Figure 7. Transmittance of Chemglaze Z306 black paint outgassing contaminants on 77 K germanium for film thicknesses of 0.11, 0.91, and 1.82 μm.**

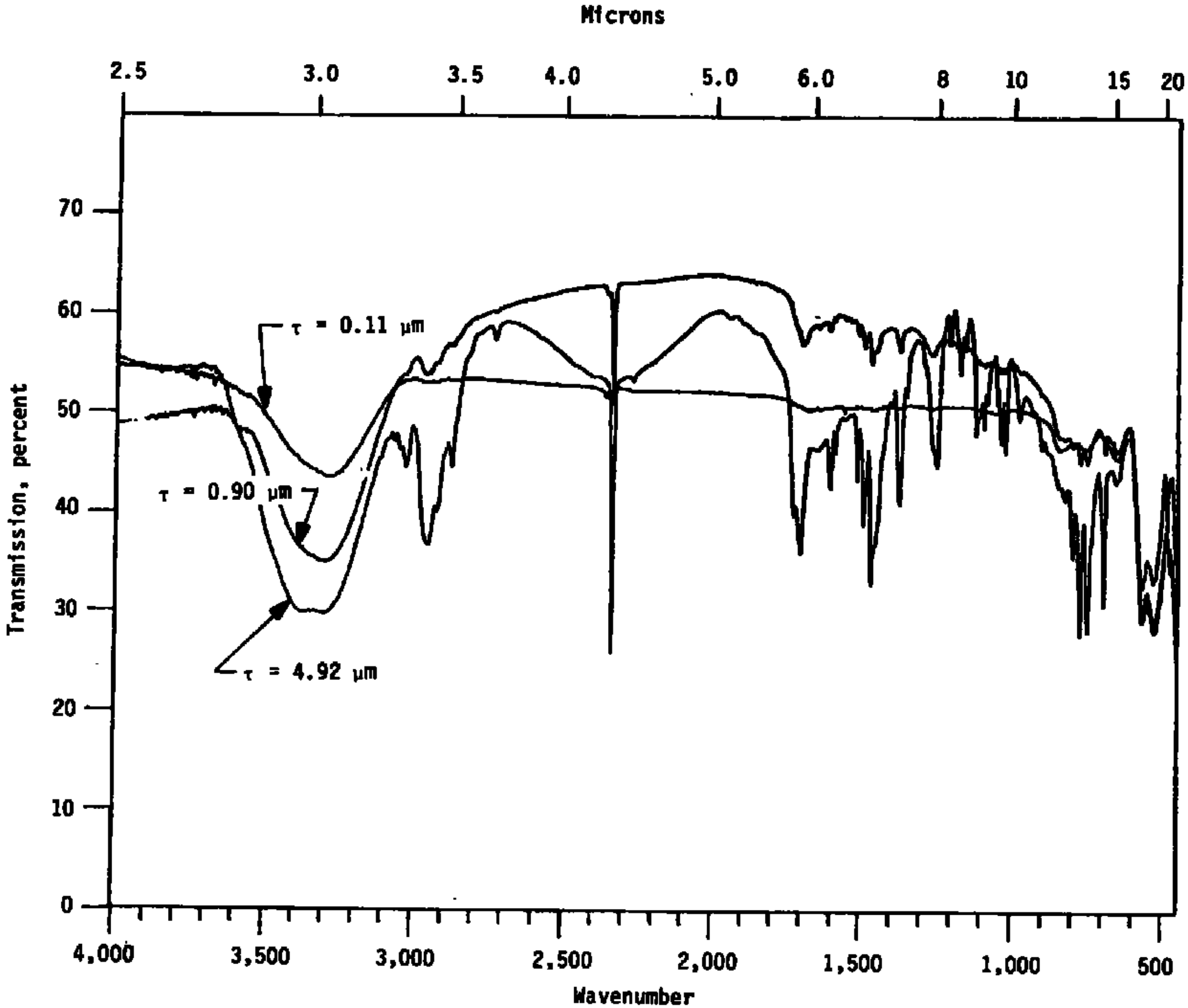



Figure 8. Transmittance of Chemglaze A276 white paint outgassing contaminants on 77 K germanium for film thicknesses of 0.11, 0.90, and 4.92 µm.

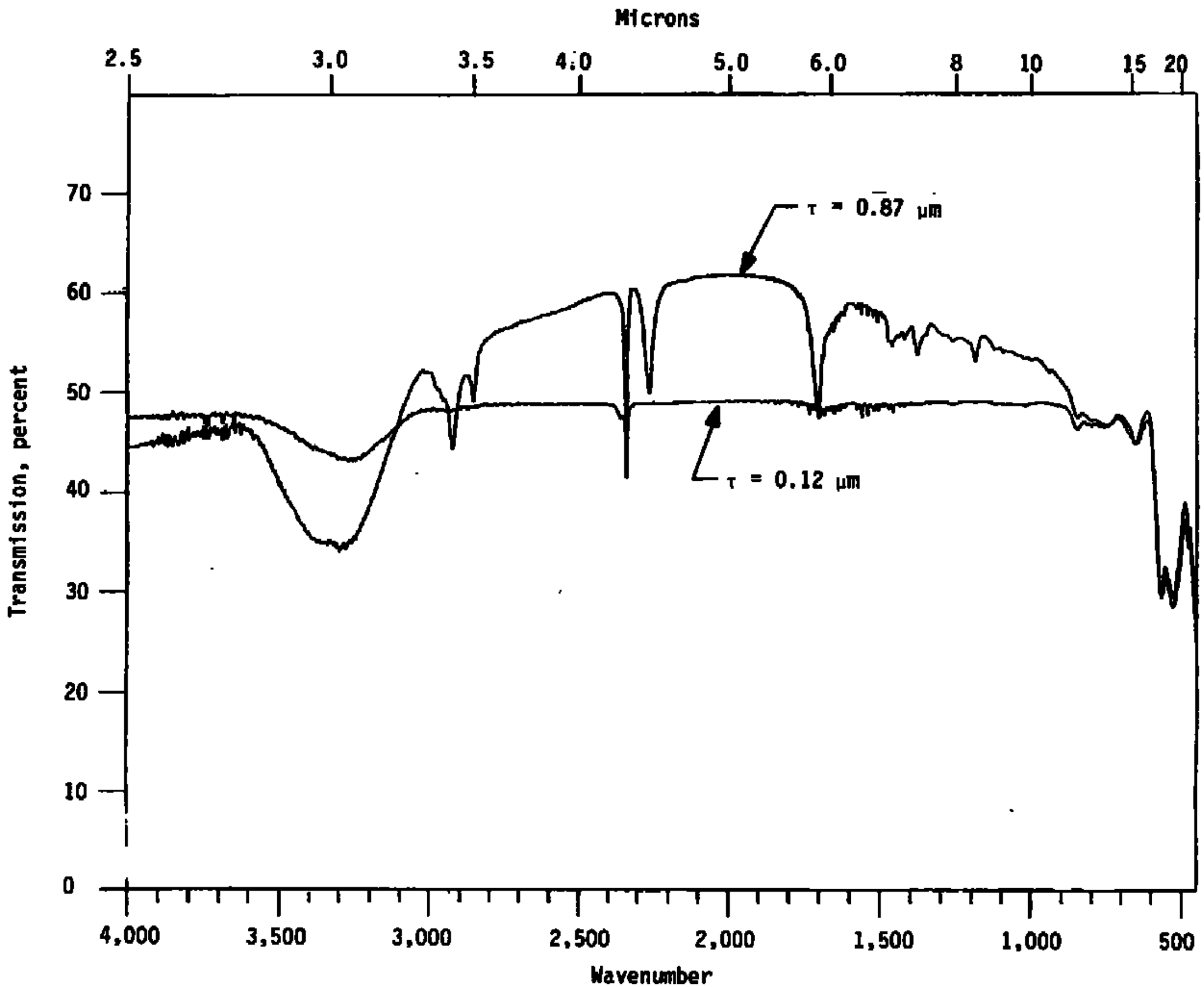



**Figure 9. Transmittance of Solithane 113 adhesive outgassing contaminants on 77 K germanium for film thicknesses of 0.12 and 0.87 $\mu$m.**

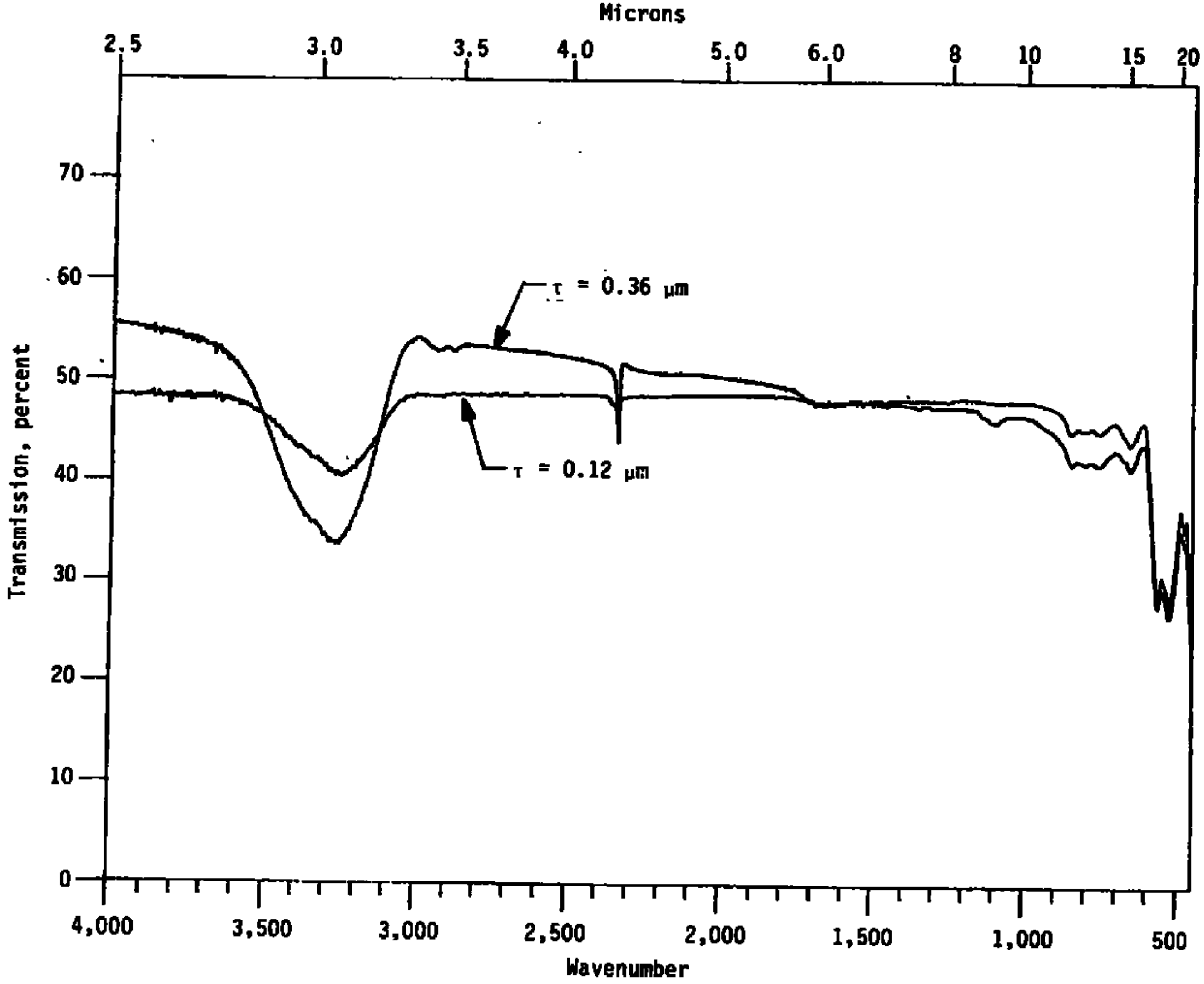



**Figure 10. Transmittance of Stycast 2850 adhesive outgassing contaminants on 77 K germanium for film thicknesses of 0.12 and 0.36 $\mu$m.**

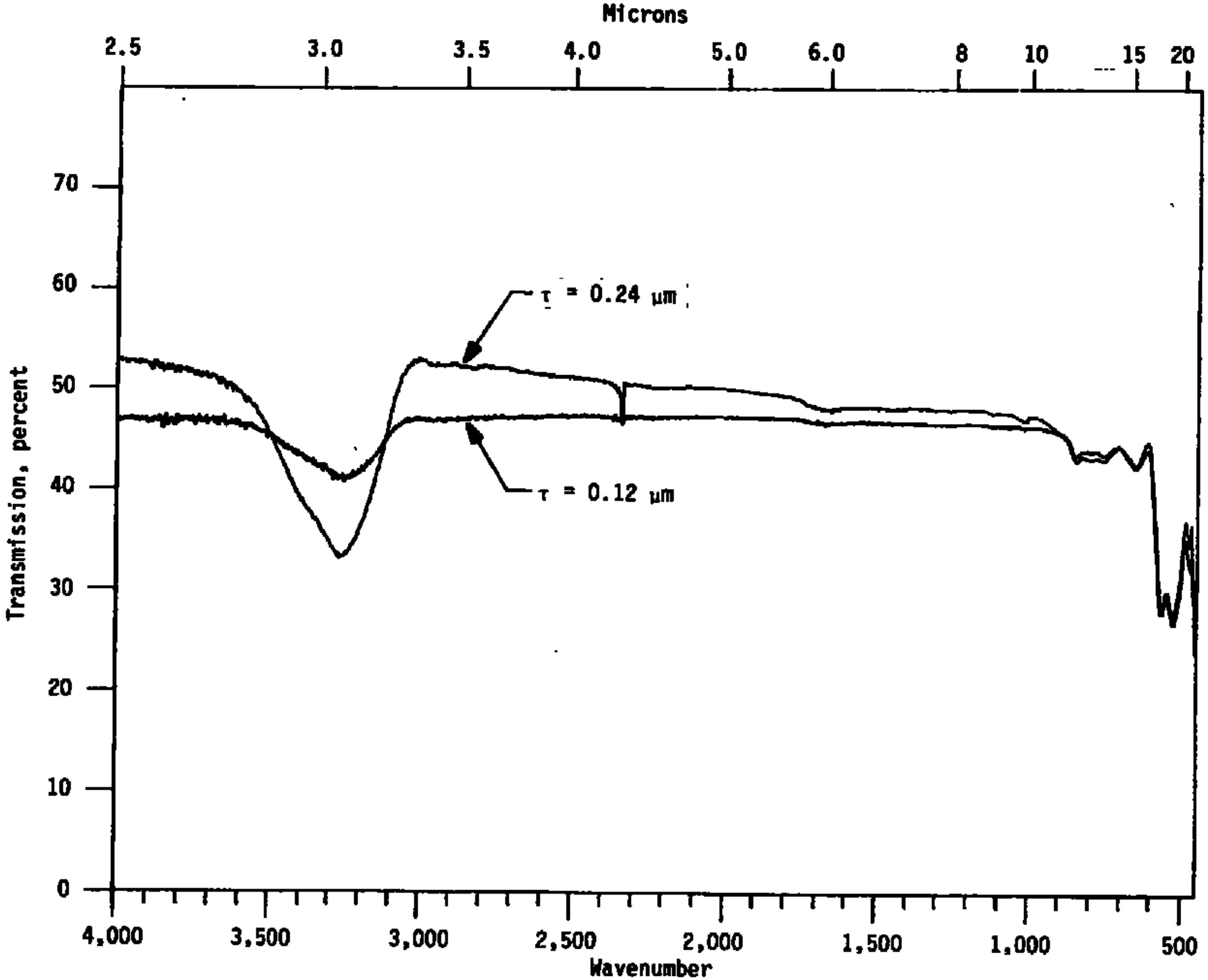



**Figure 11. Transmittance of Epoxi-patch adhesive outgassing contaminants on 77 K germanium for film thicknesses of 0.12 and 0.24 $\mu$m.**

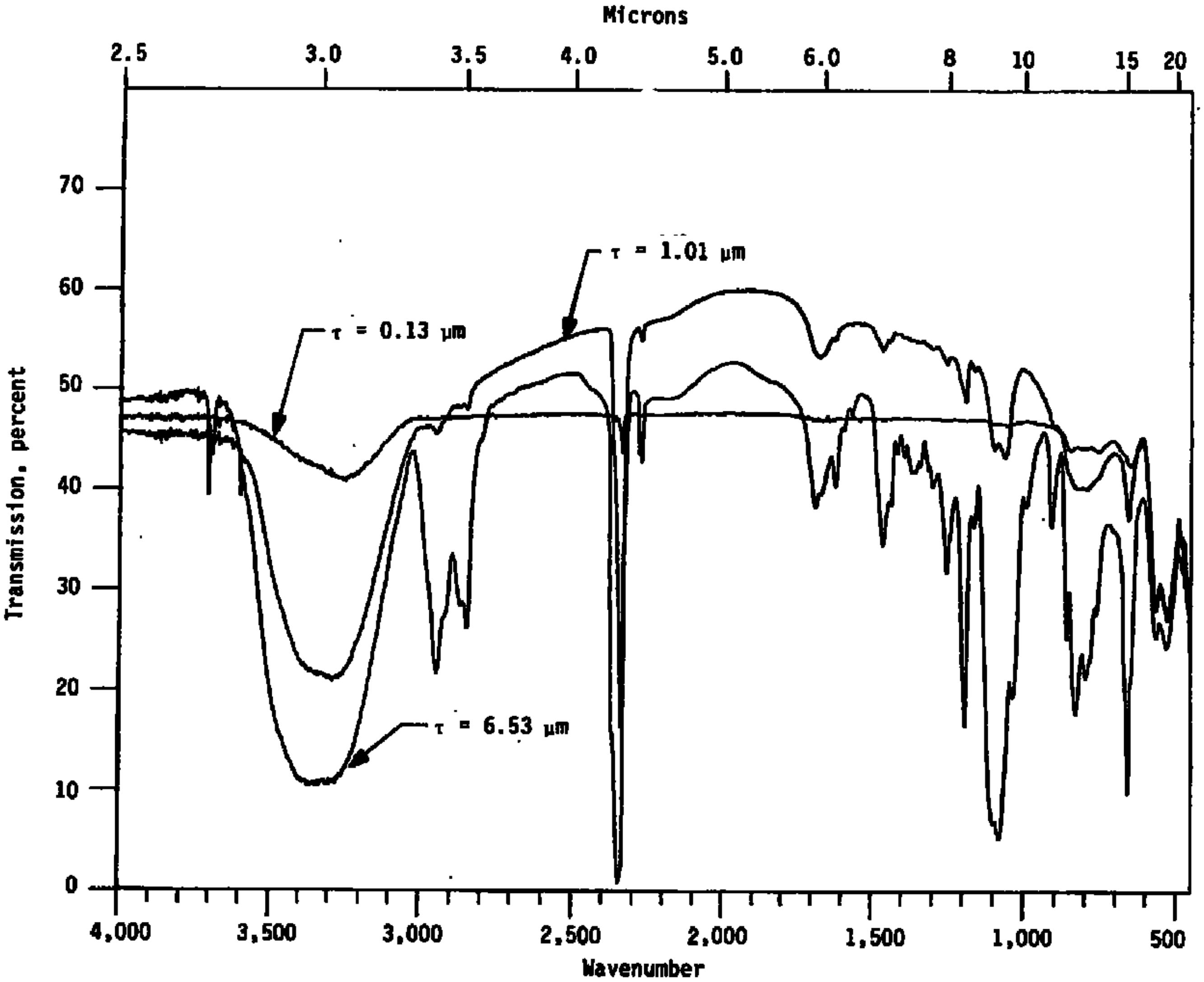



Figure 12. Transmittance of Crest 7450 adhesive outgassing contaminants on 77 K germanium for film thicknesses of 0.13, 1.01, and 6.53 $\mu$m.

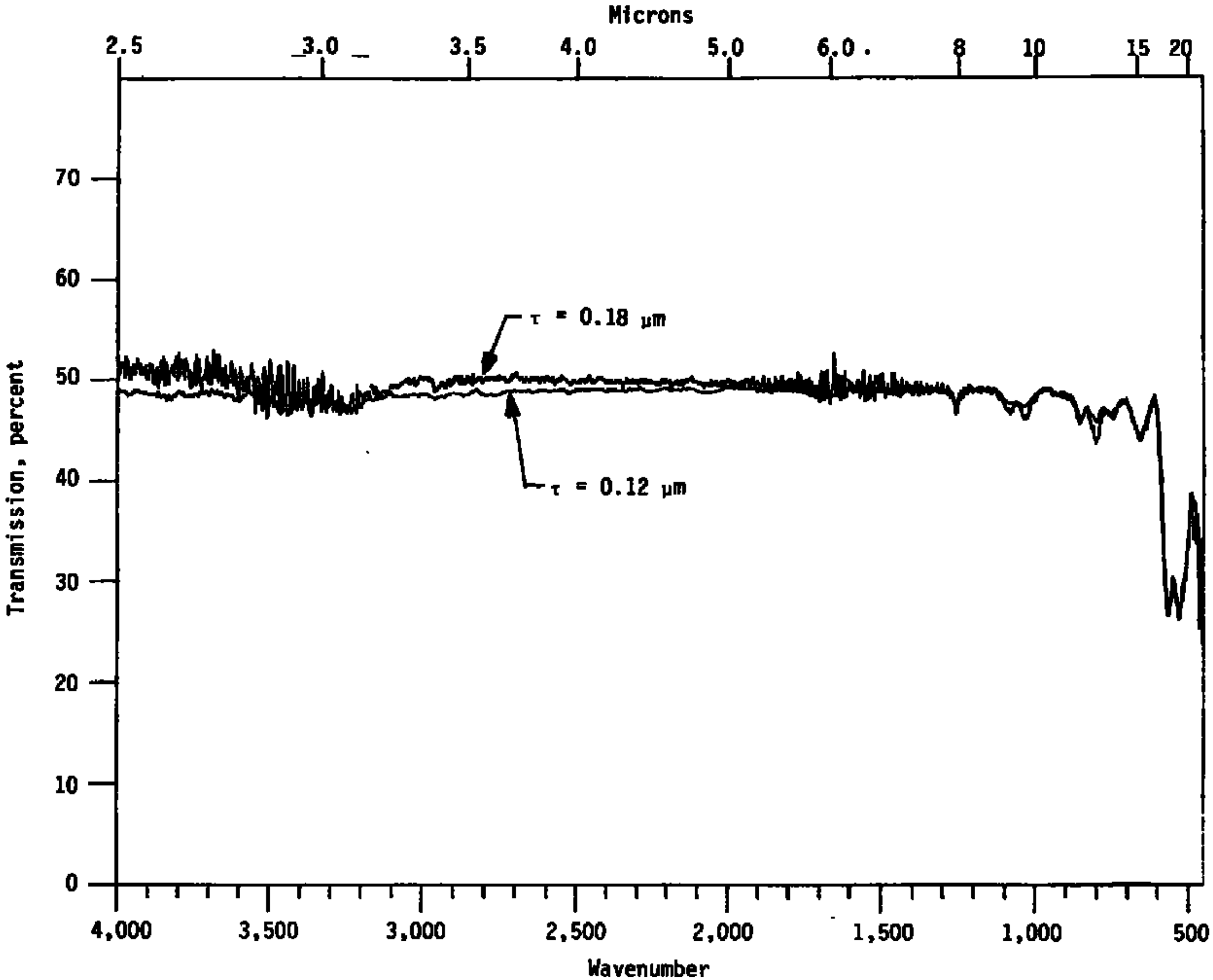



**Figure 13. Transmittance of Mocap self-fusing tape outgassing contaminants on 77 K germanium for film thicknesses of 0.12 and 0.18 $\mu$m.**

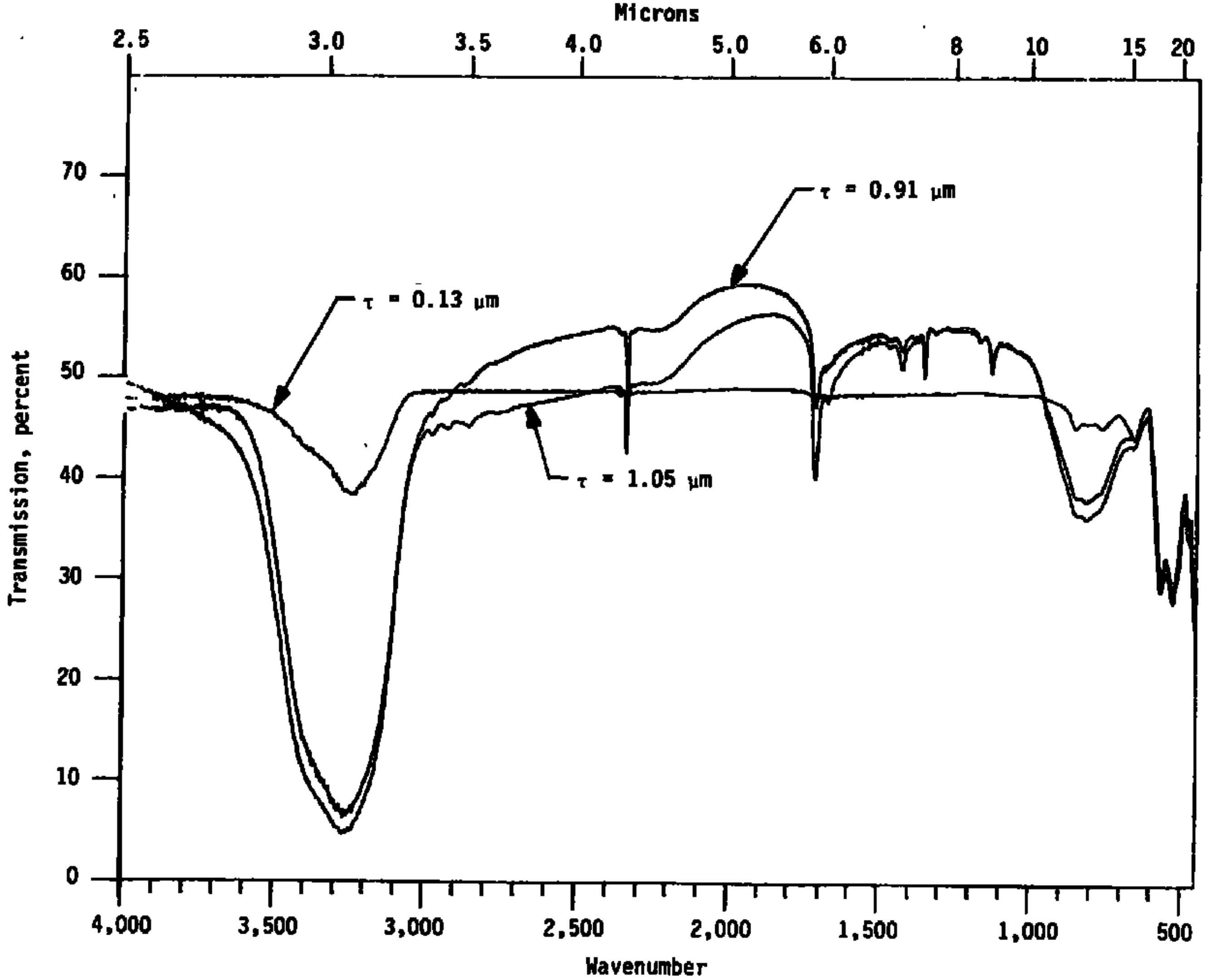



Figure 14. Transmittance of Mylar film (5 mil) outgassing contaminants on 77 K germanium for film thicknesses of 0.13, 0.91, and 1.05 µm.

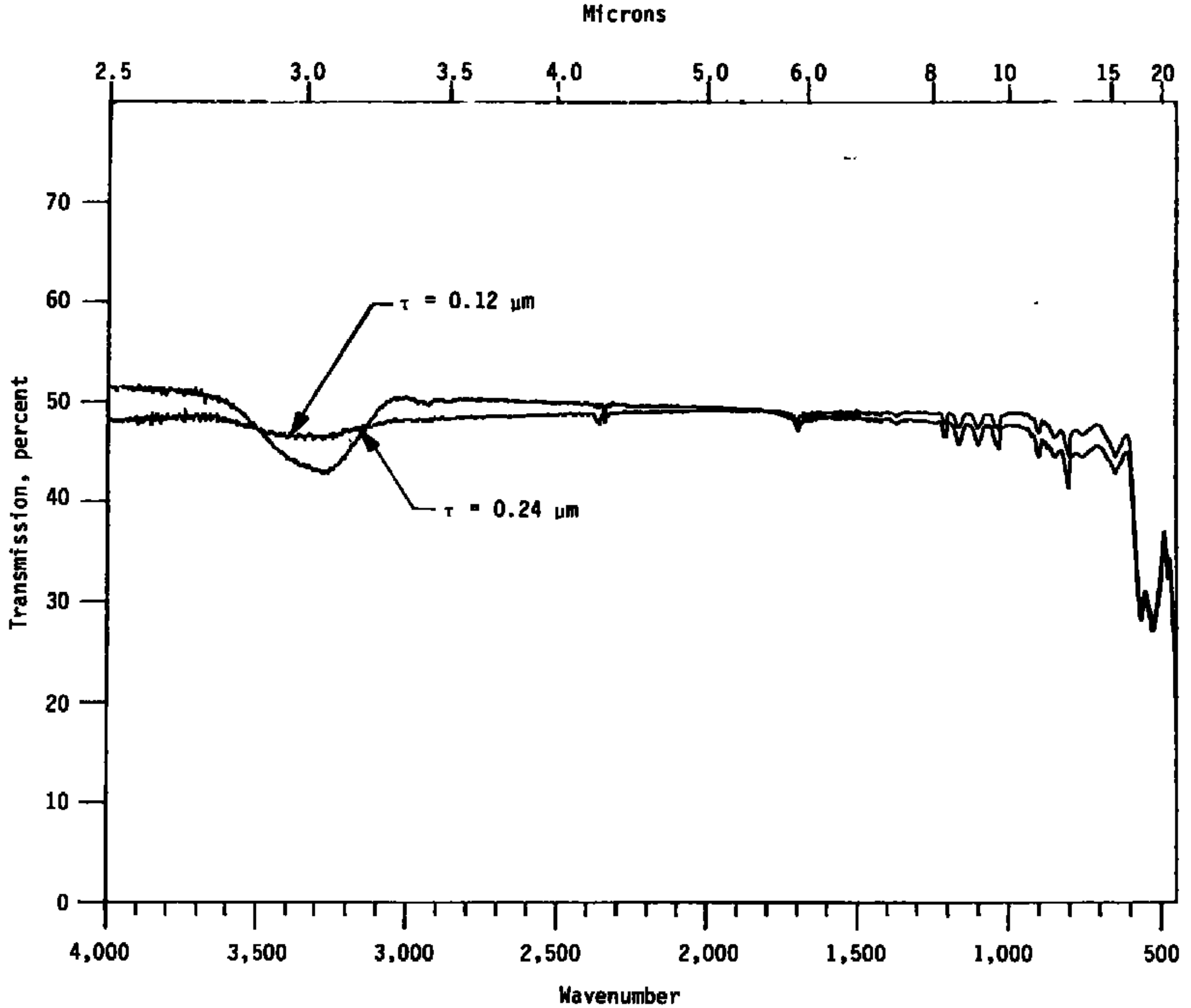



**Figure 15. Transmittance of FEP Teflon (1 mil) outgassing contaminants on 77 K germanium for film thicknesses of 0.12 and 0.24 $\mu$m.**

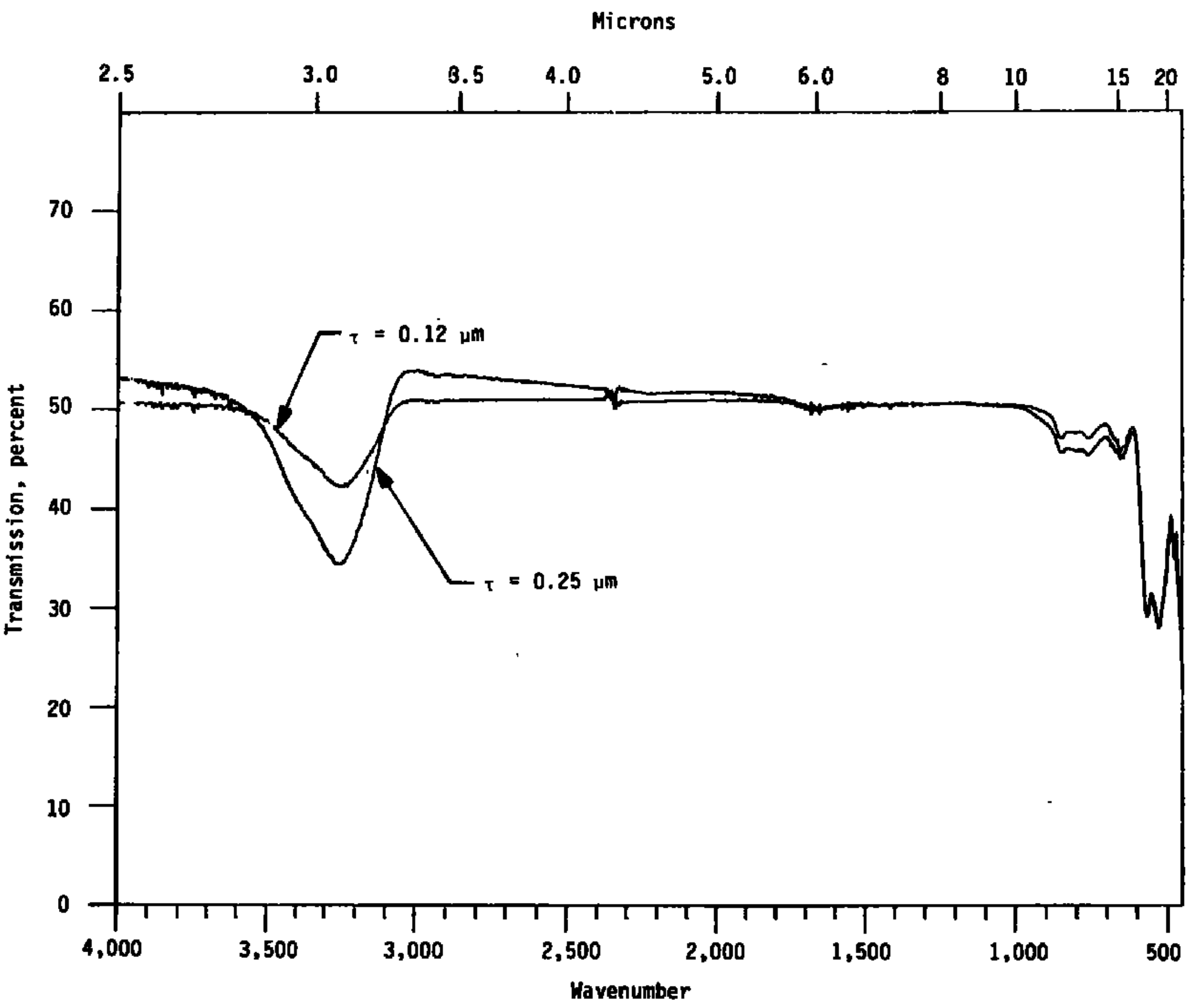



**Figure 16. Transmittance of PEEK/AS4 composite outgassing contaminants on 77 K germanium for film thicknesses of 0.12 and 0.25 $\mu$m.**

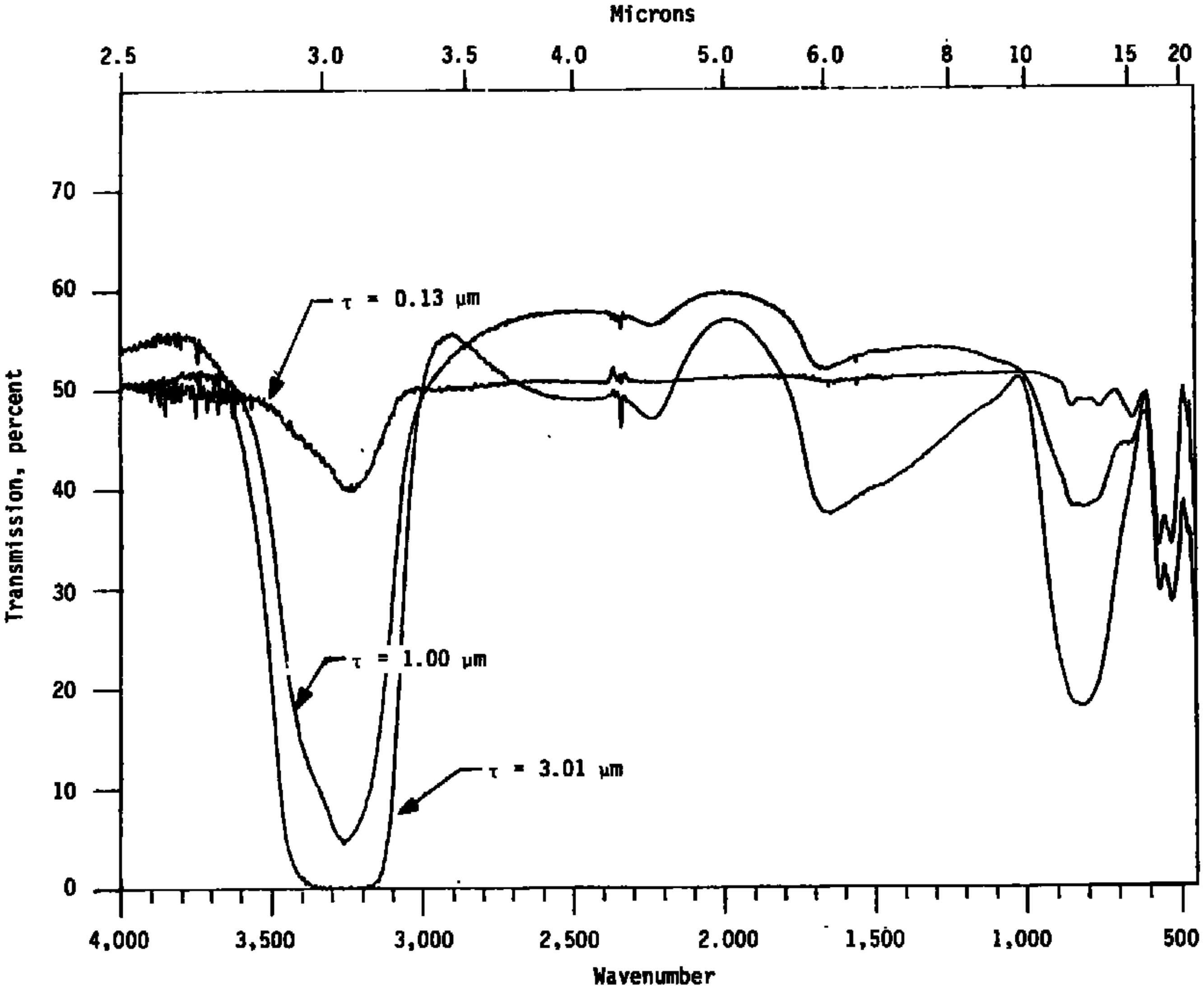



**Figure 17. Transmittance of J2/AS4 composite outgassing contaminants on 77 K germanium for film thicknesses of 0.13, 1.00, and 3.01 $\mu$m.**

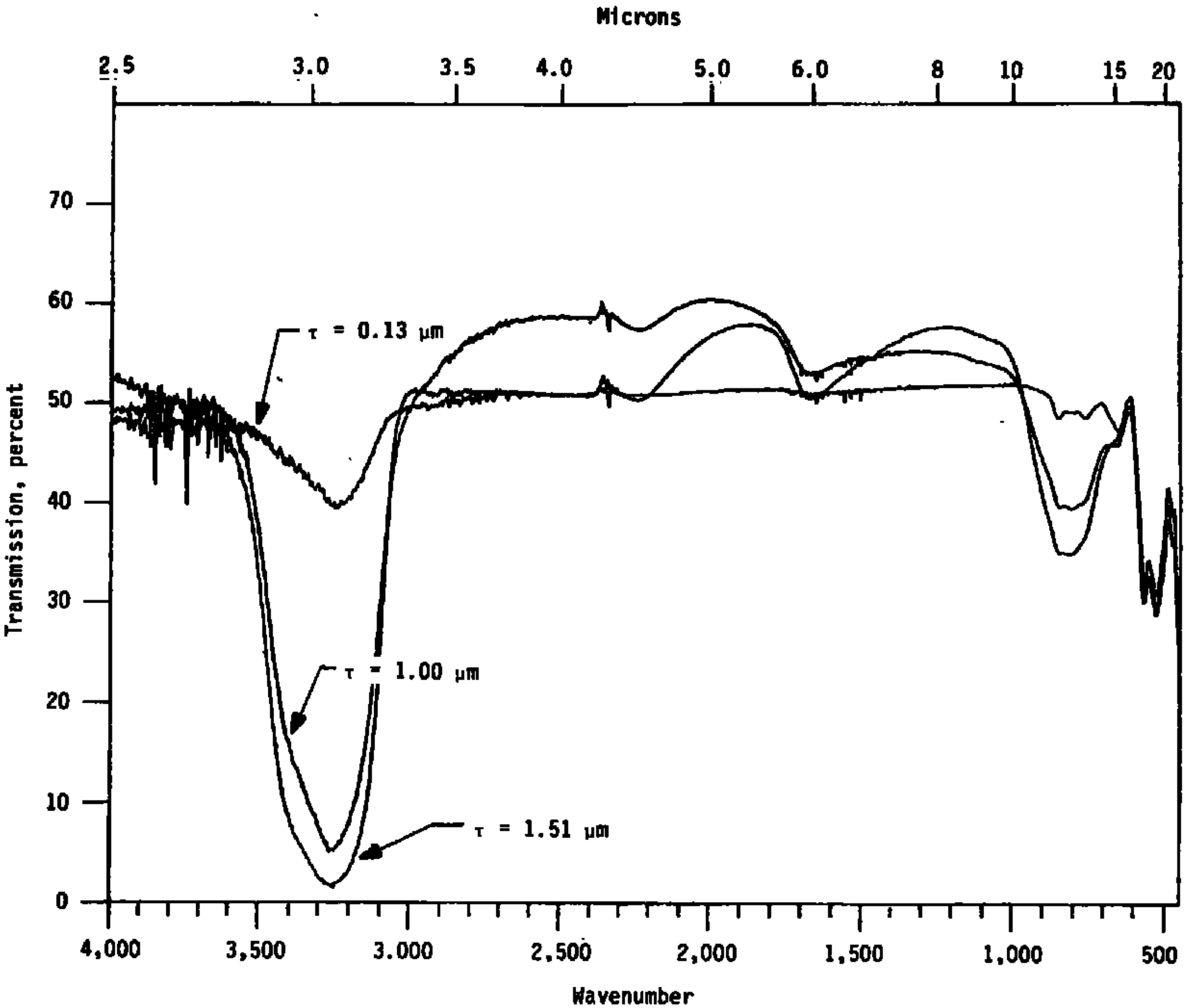



**Figure 18. Transmittance of EP30LI composite outgassing contaminants on 77 K germanium for film thicknesses of 0.13, 1.00, and 1.51 $\mu$m.**

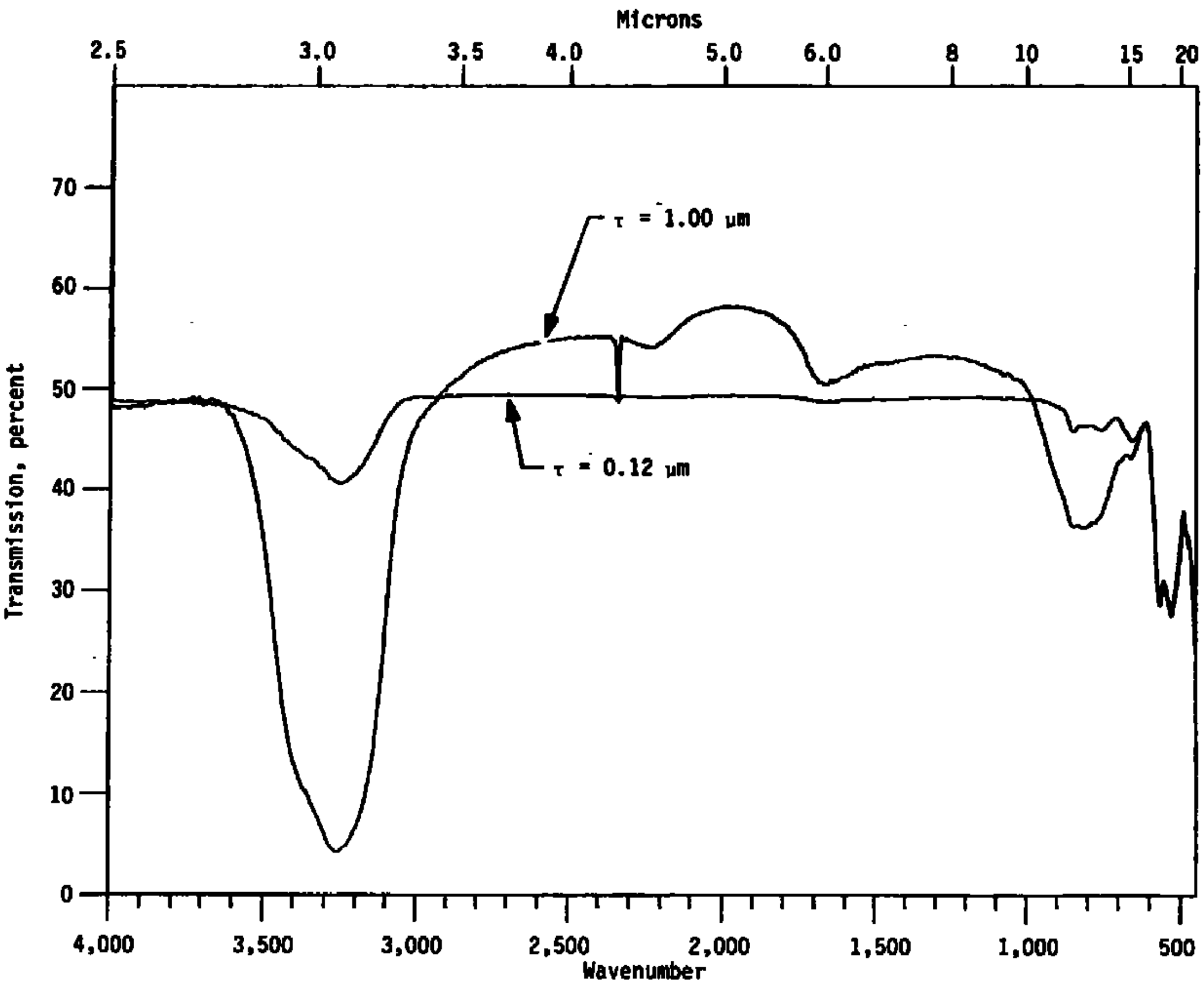



**Figure 19. Transmittance of graphite epoxy outgassing contaminants on 77 K germanium for film thicknesses of 0.12 and 1.00 $\mu$m.**

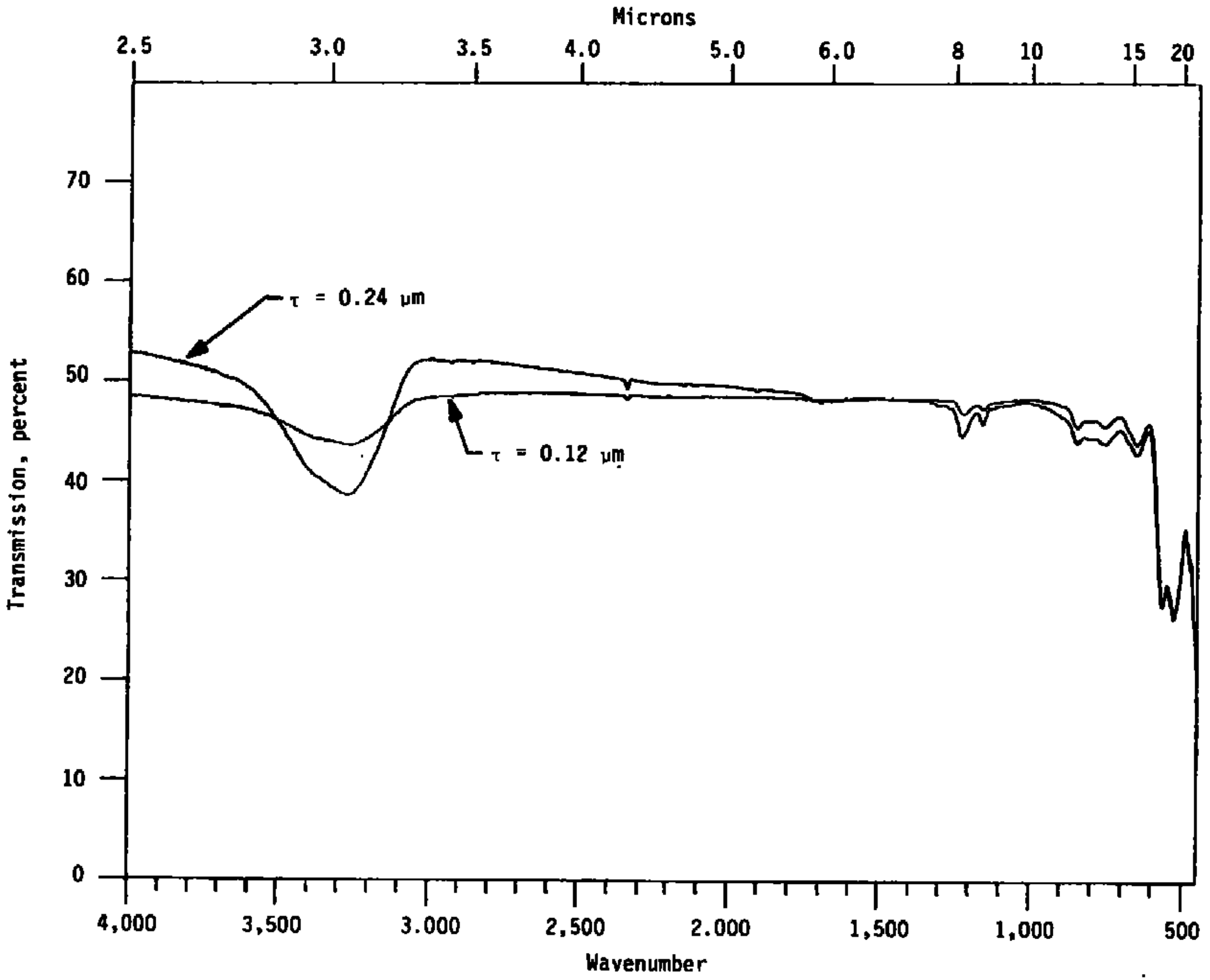



**Figure 20. Transmittance of Braycote 600 grease outgassing contaminants on 77 K germanium for film thicknesses of 0.12 and 0.24 $\mu$m.**

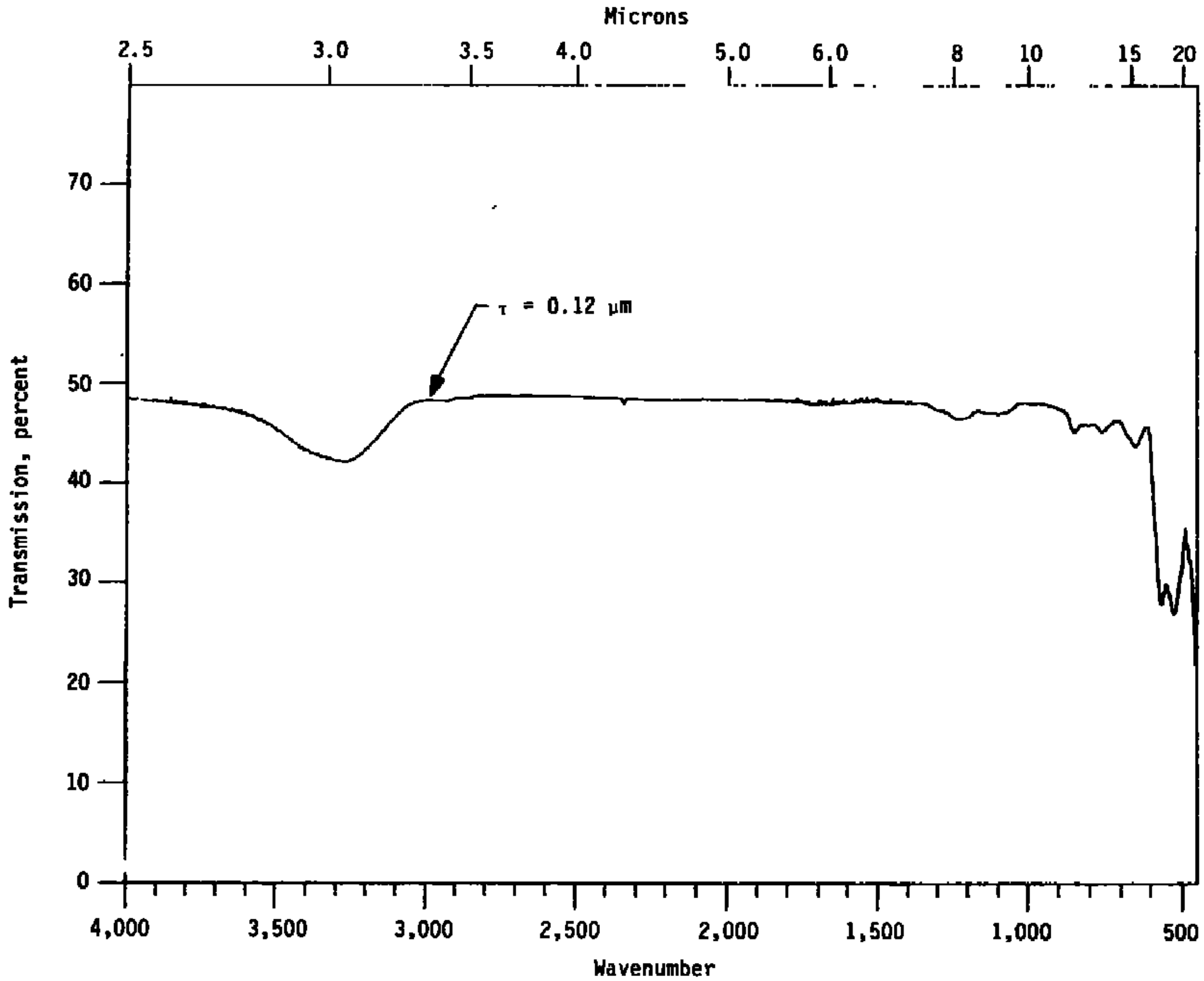



**Figure 21. Transmittance of Brayco 815Z oil outgassing contaminants on 77 K germanium for a film thickness of 0.12 $\mu$m.**

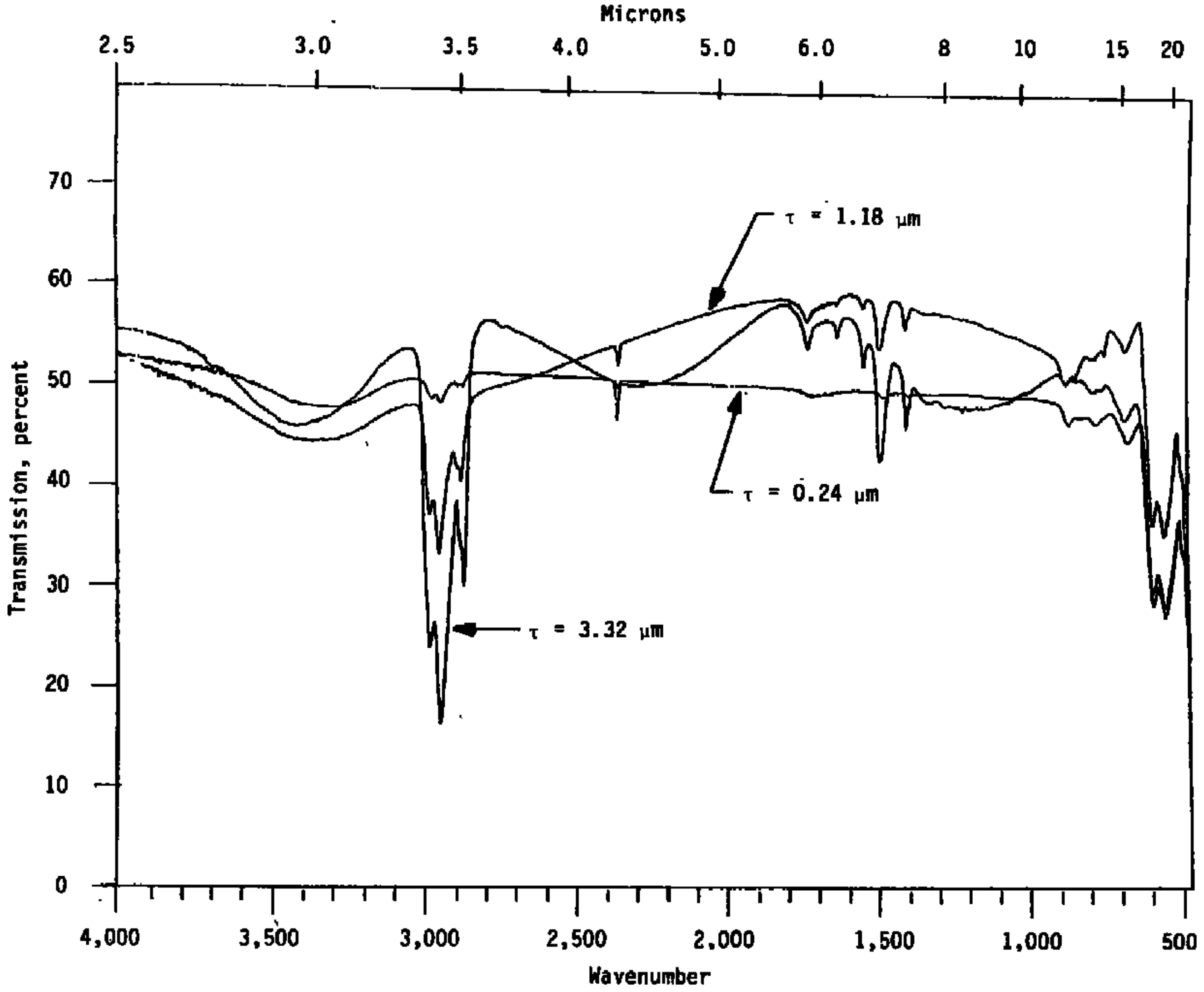



**Figure 22. Transmittance of Vac-Kote oil outgassing contaminants on 77 K germanium for film thicknesses of 0.24, 1.18, and 3.32 μm.**

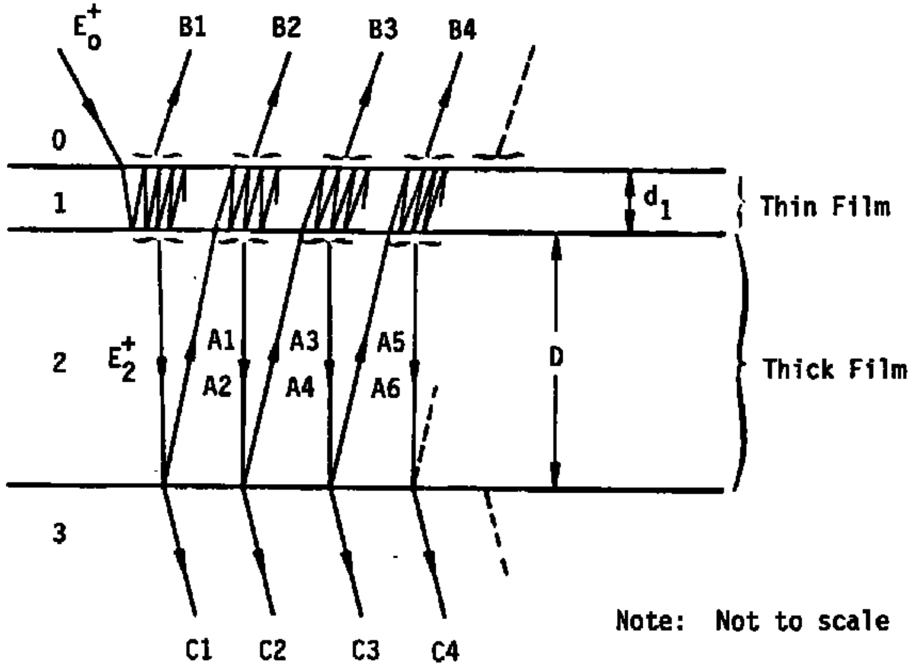



**Figure 23. Geometry depicting analytical model for a thin film formed upon a thick film.**

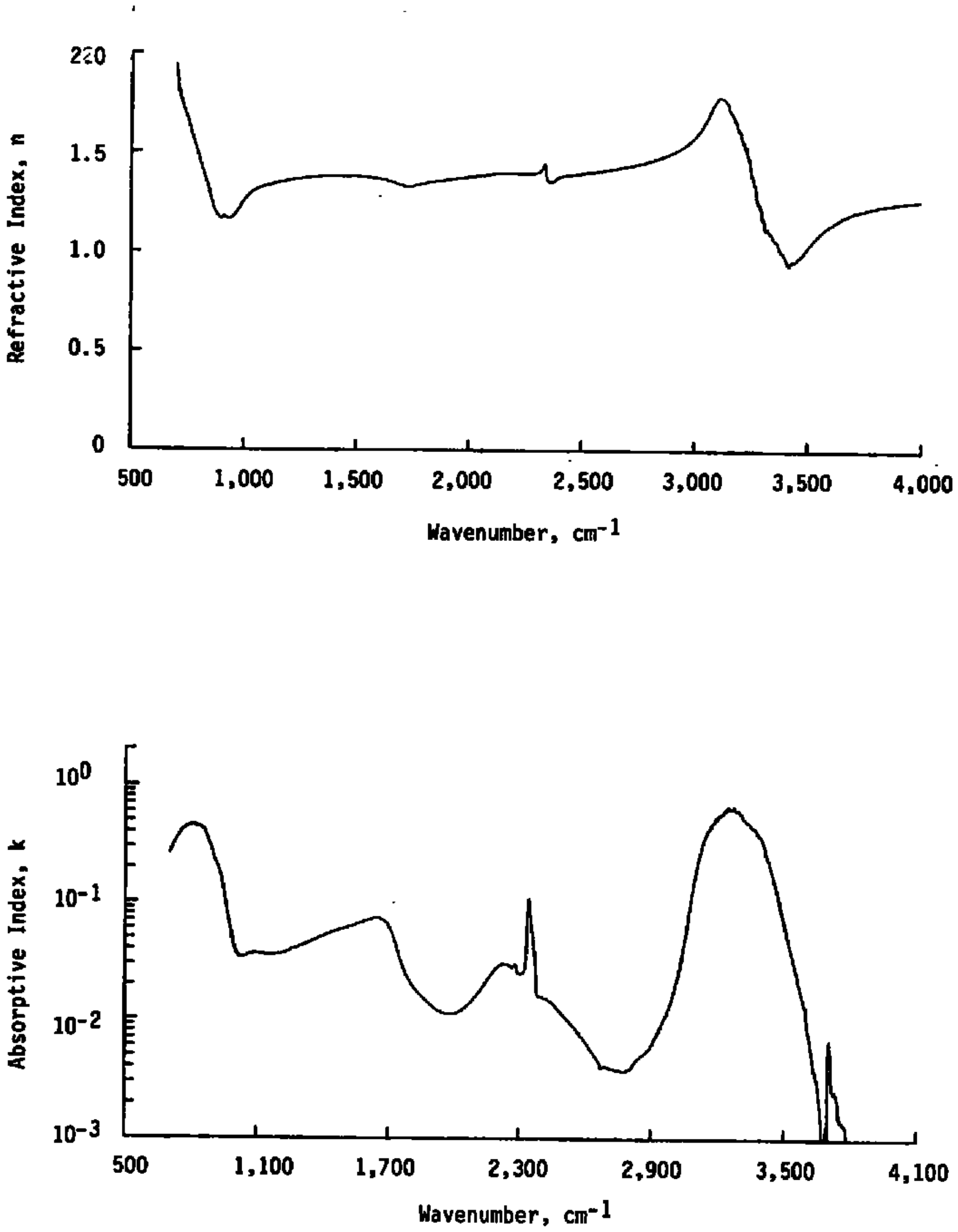



**Figure 24. Optical properties for outgassing products of developmental Lockheed thermal control coating 0200, heated to 125°C.**

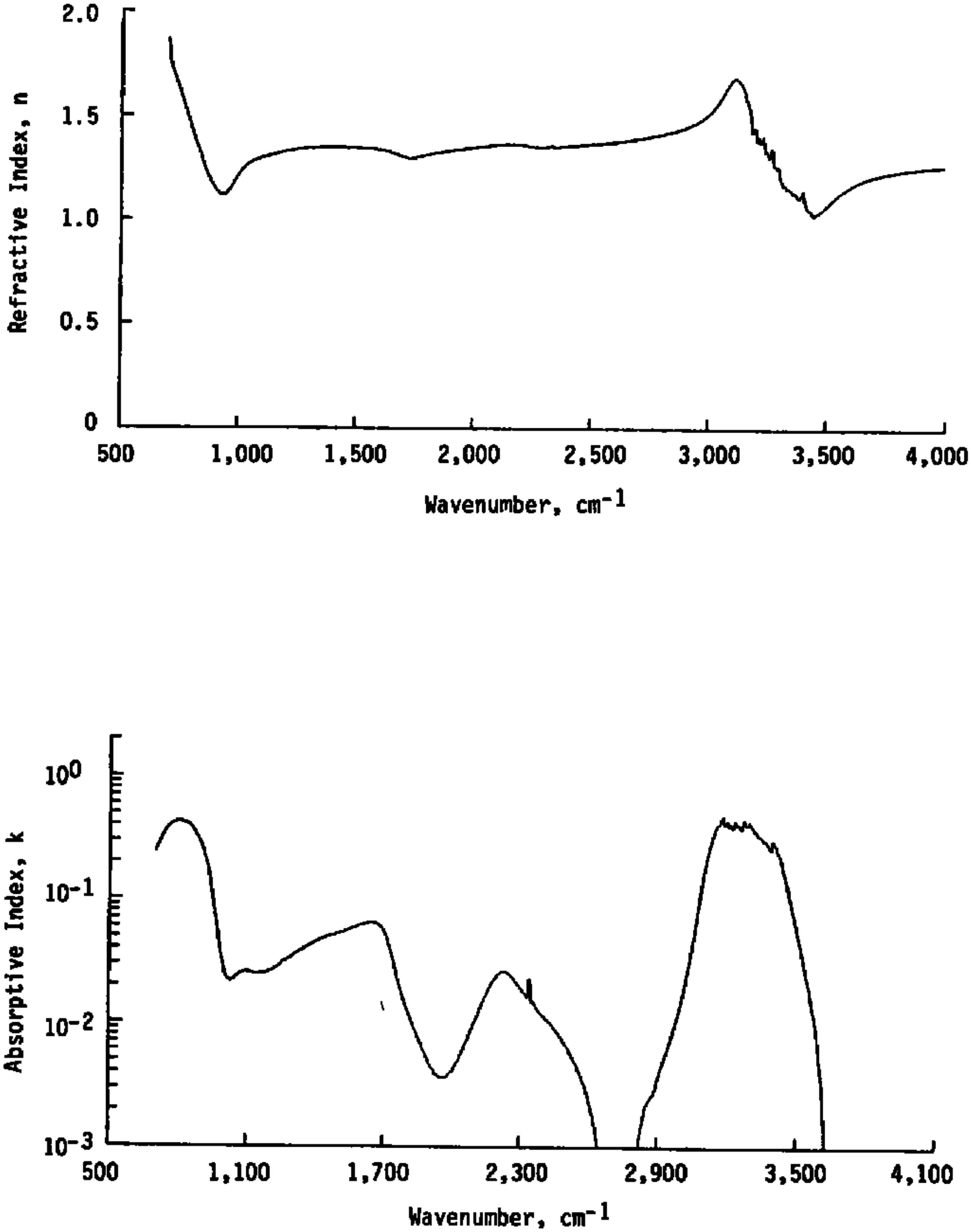
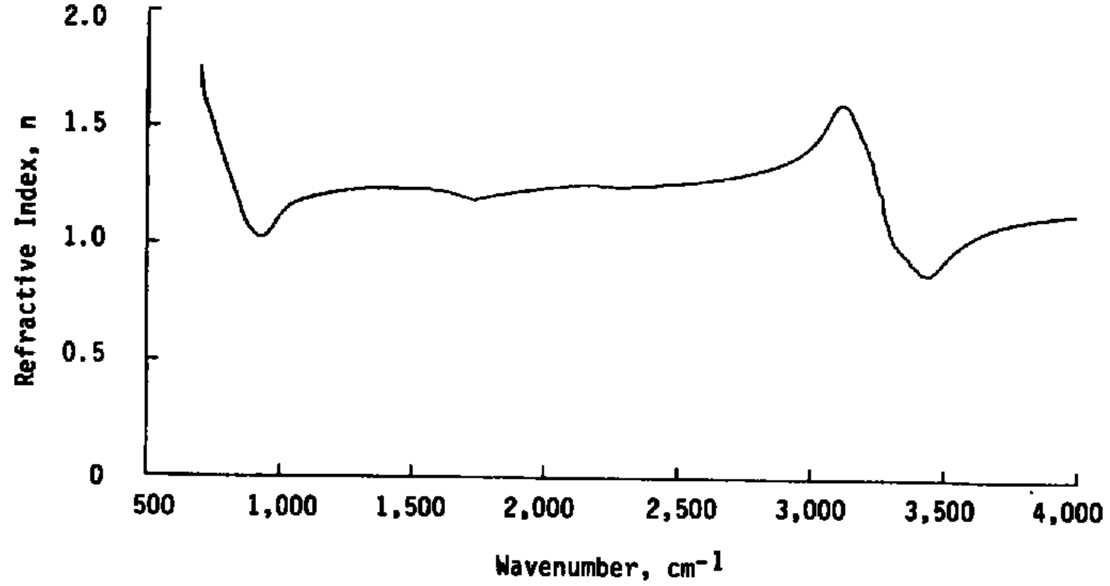



**Figure 25. Optical properties for outgassing products of developmental Lockheed thermal control coating 0200, heated to 75°C.**



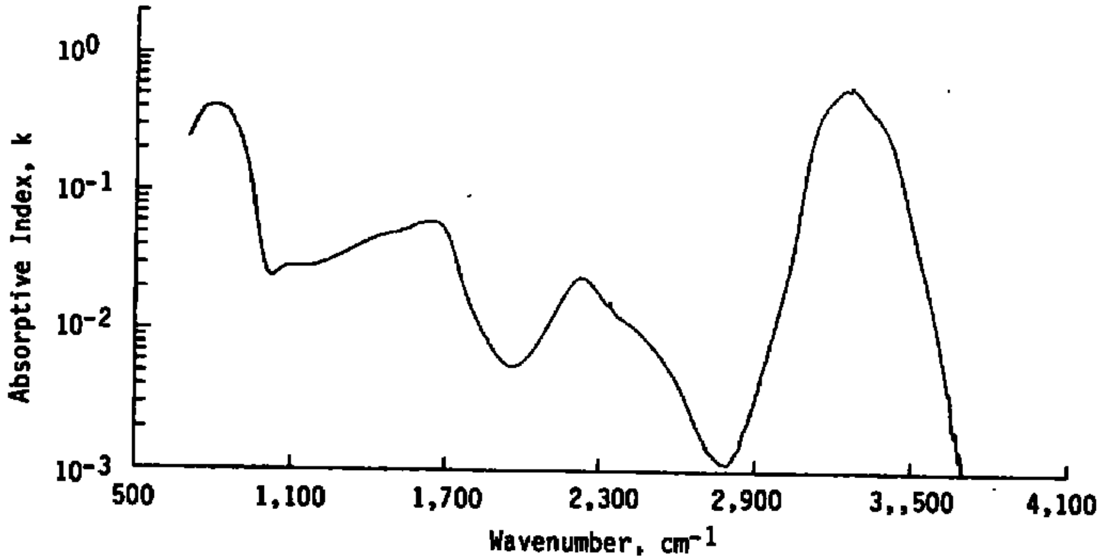
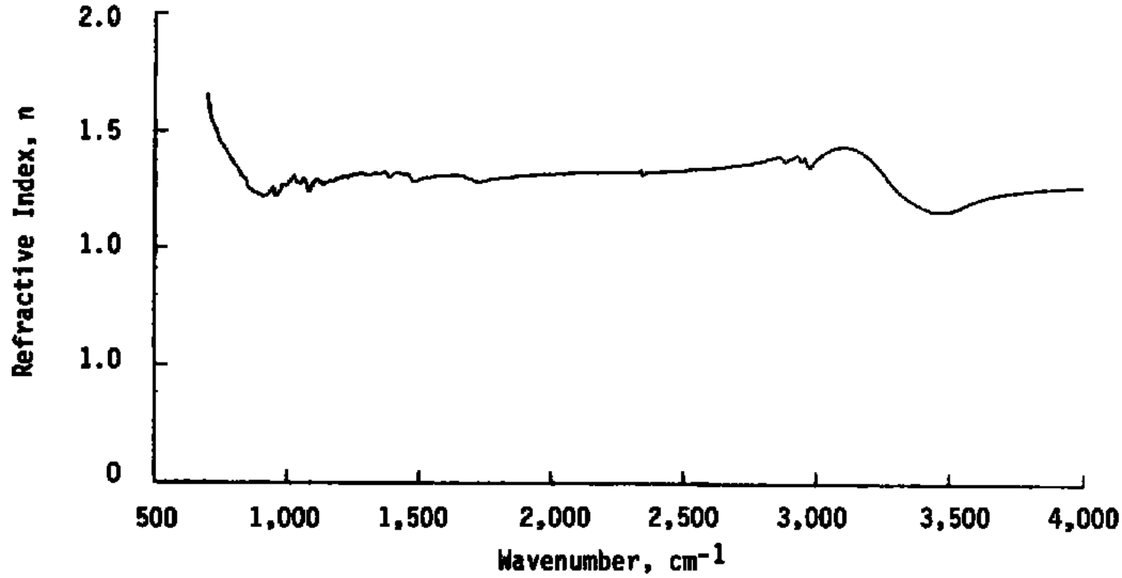




**Figure 26. Optical properties for outgassing products of developmental Lockheed thermal control coating 0100, heated to 125°C.**



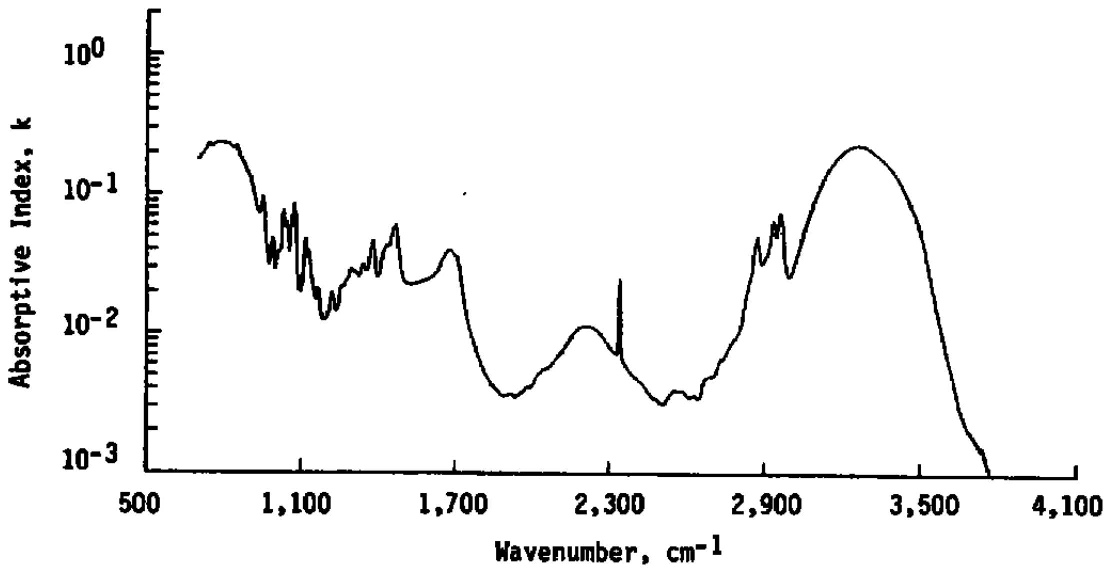




**Figure 27. Optical properties for outgassing products of develpmental Lockheed thermal control coating 0300, heated to 125°C.**

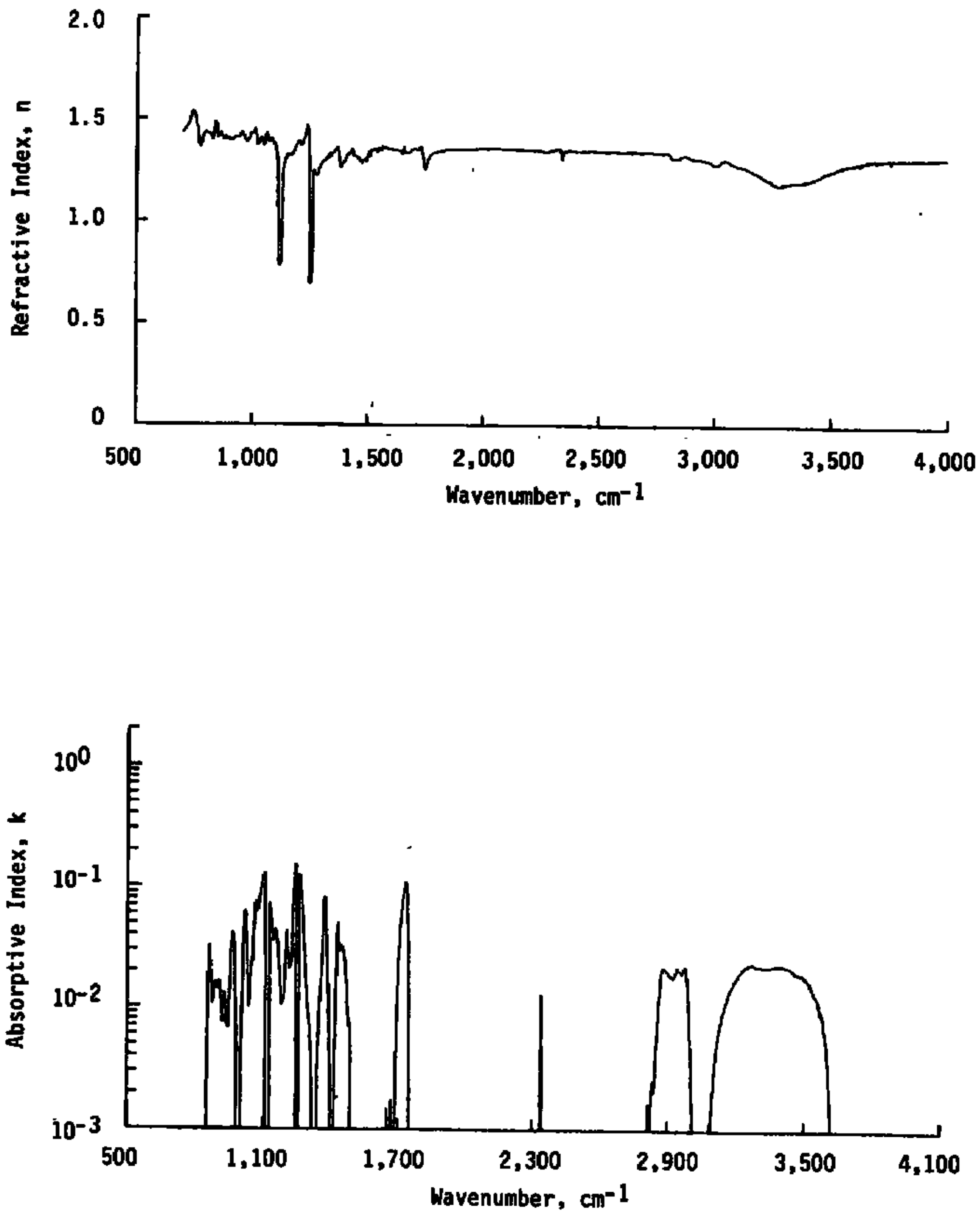



**Figure 28. Optical properties for Chemglaze Z306 black paint outgassing products.**

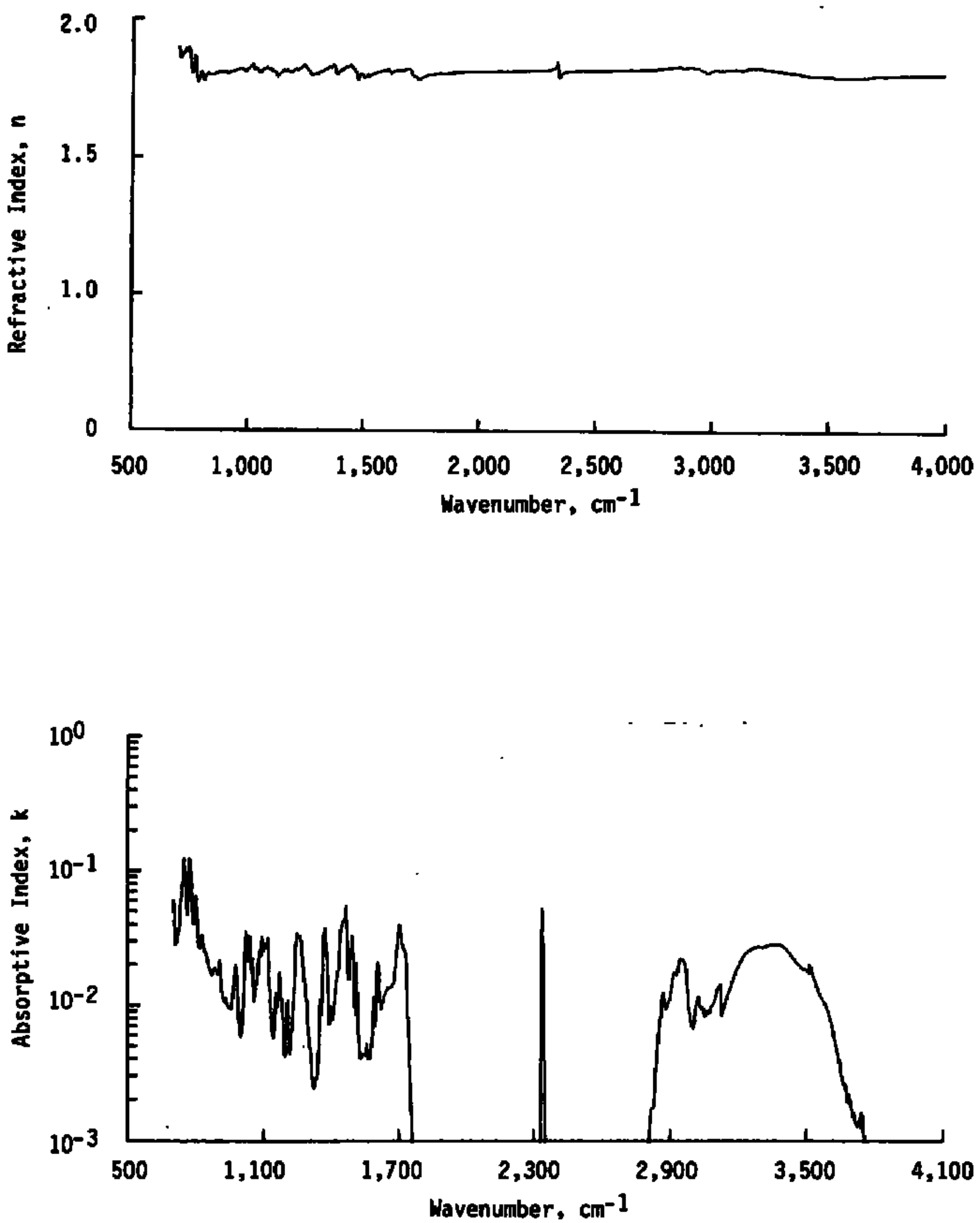



**Figure 29. Optical properties for Chemglaze A276 white paint outgassing products.**

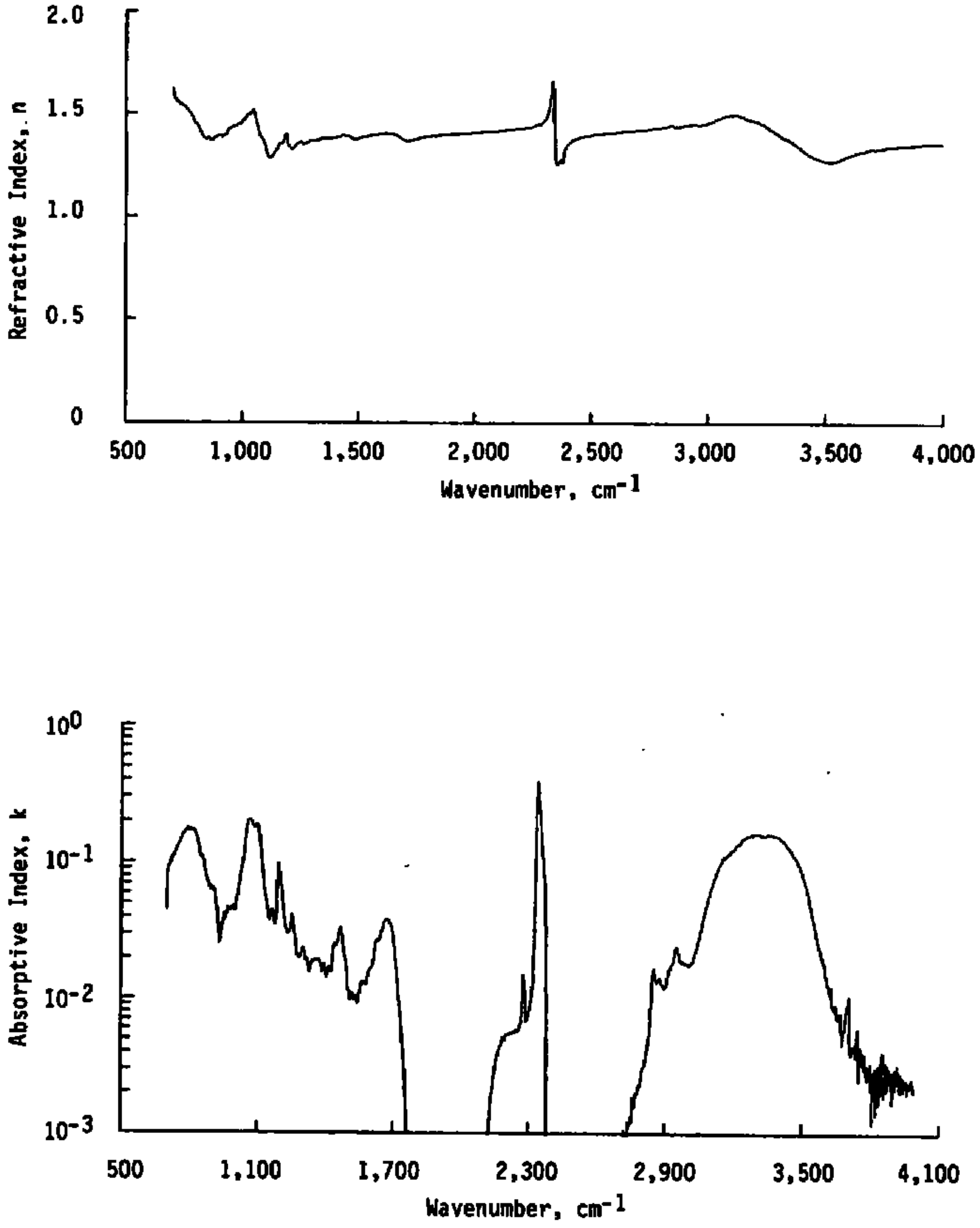



**Figure 30. Optical properties for Crest 7450 adhesive outgassing products.**

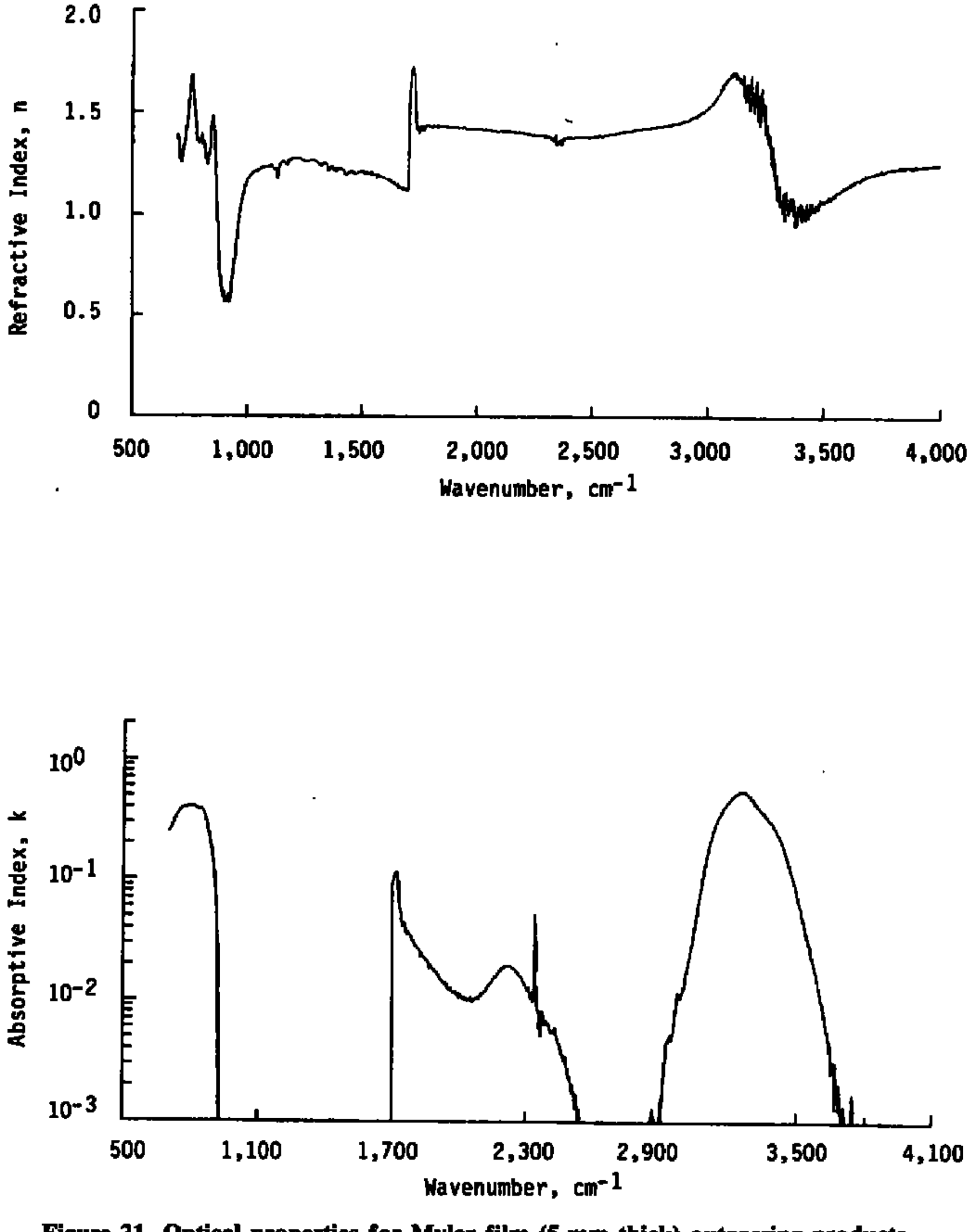



Figure 31. Optical properties for Mylar film (5-mm thick) outgassing products.

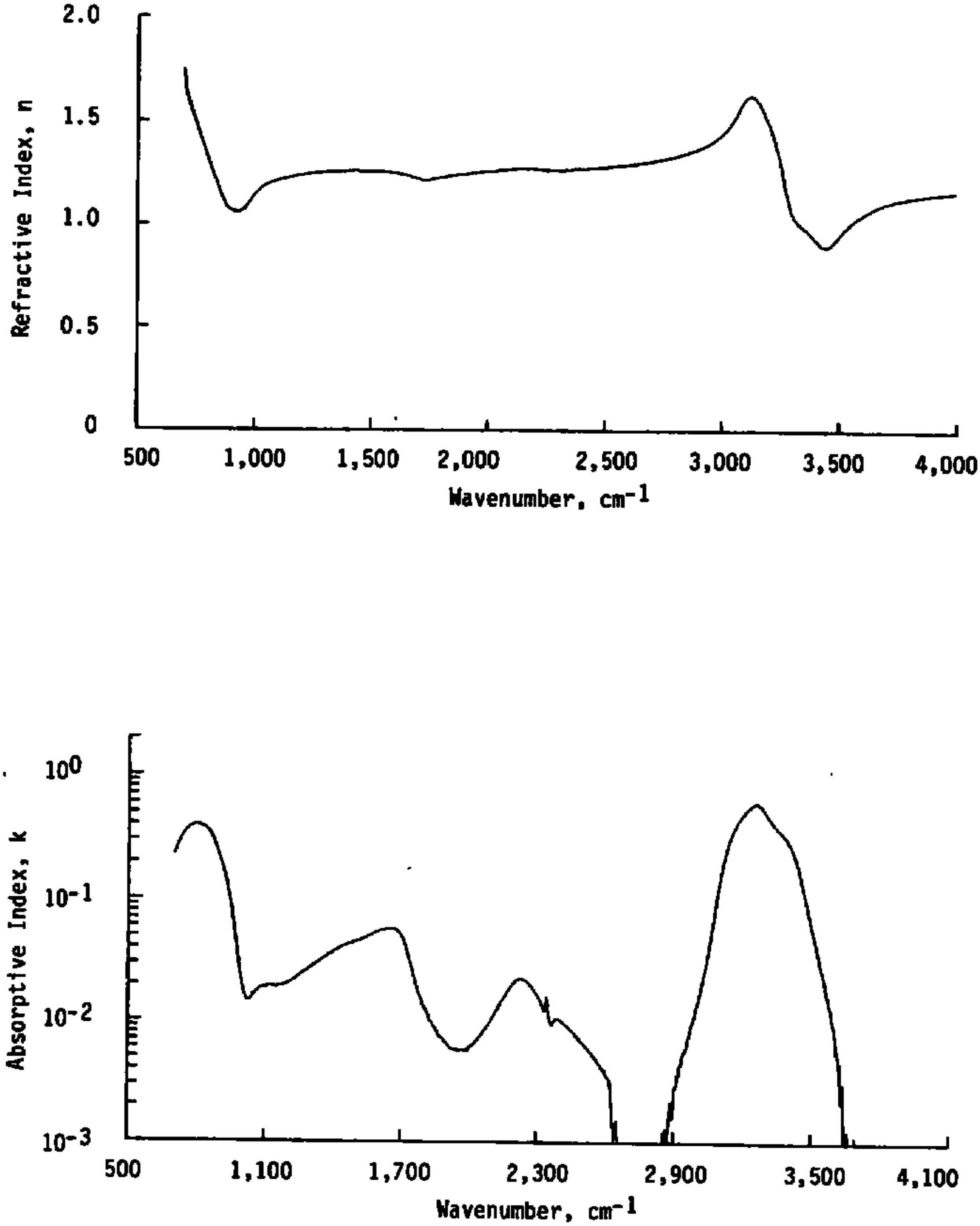



**Figure 32. Optical properties for J2/AS4 composite outgassing products.**

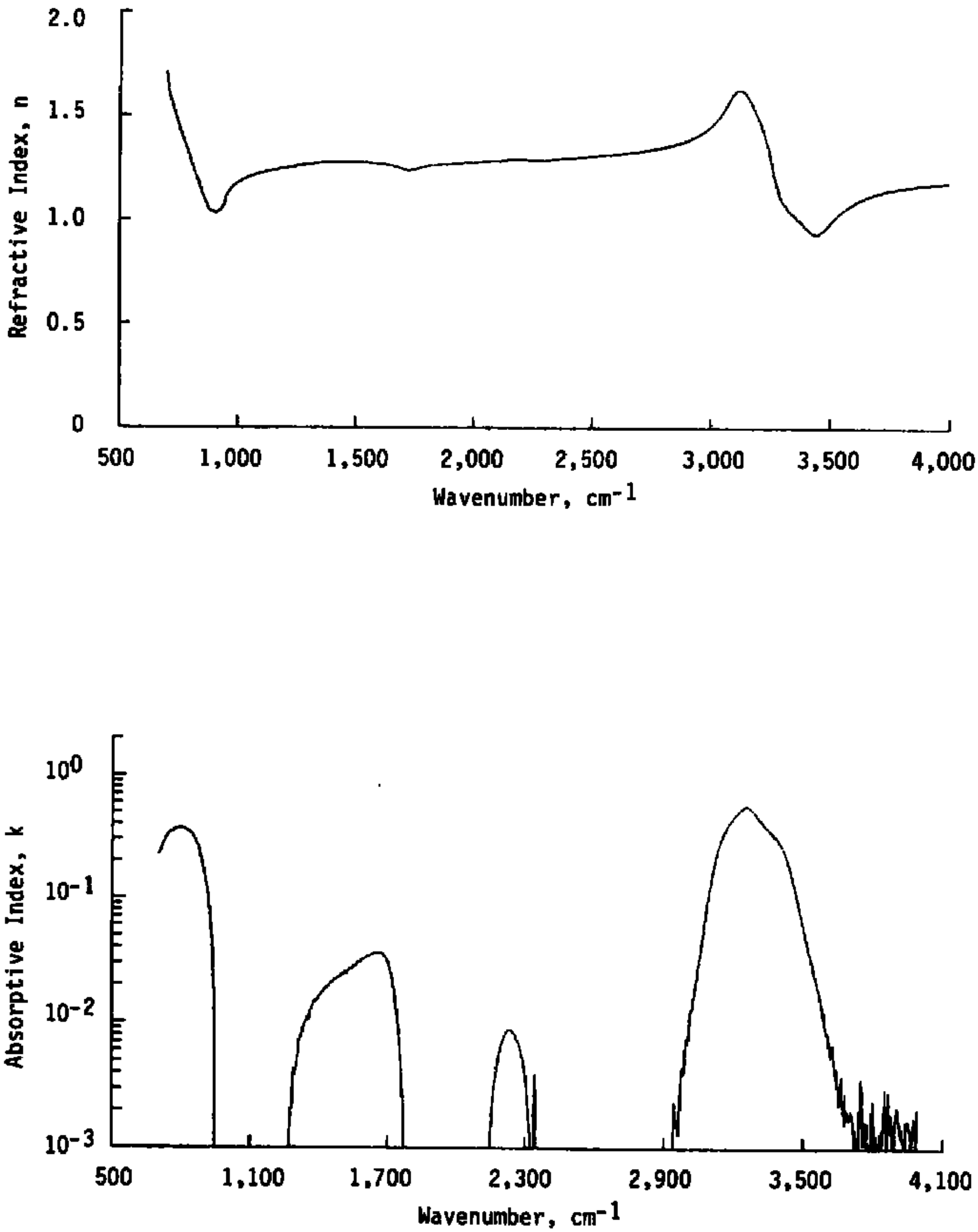
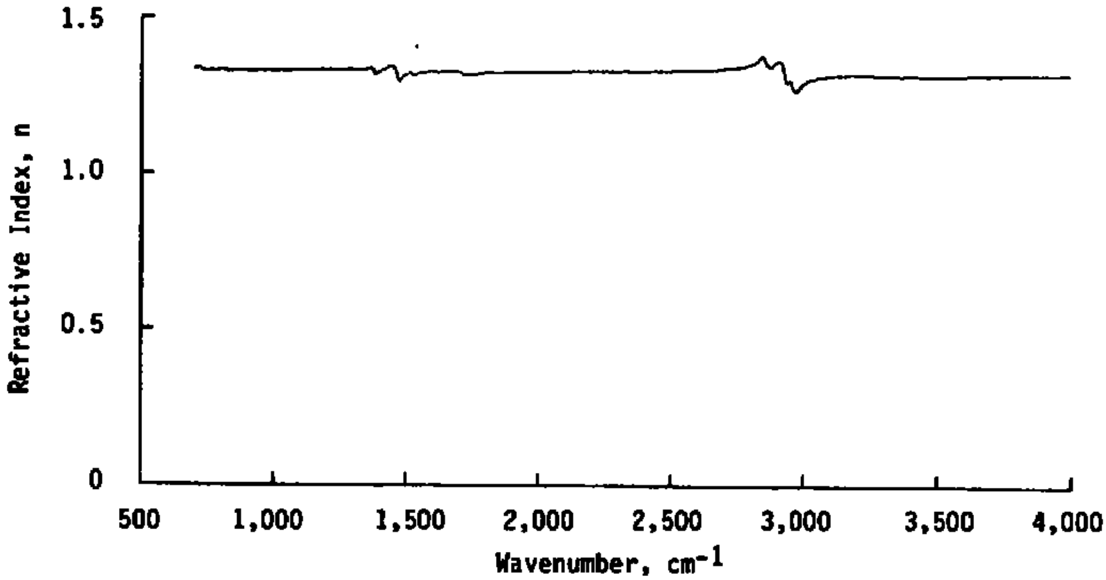



**Figure 33. Optical properties for EP30LI composite outgassing products.**



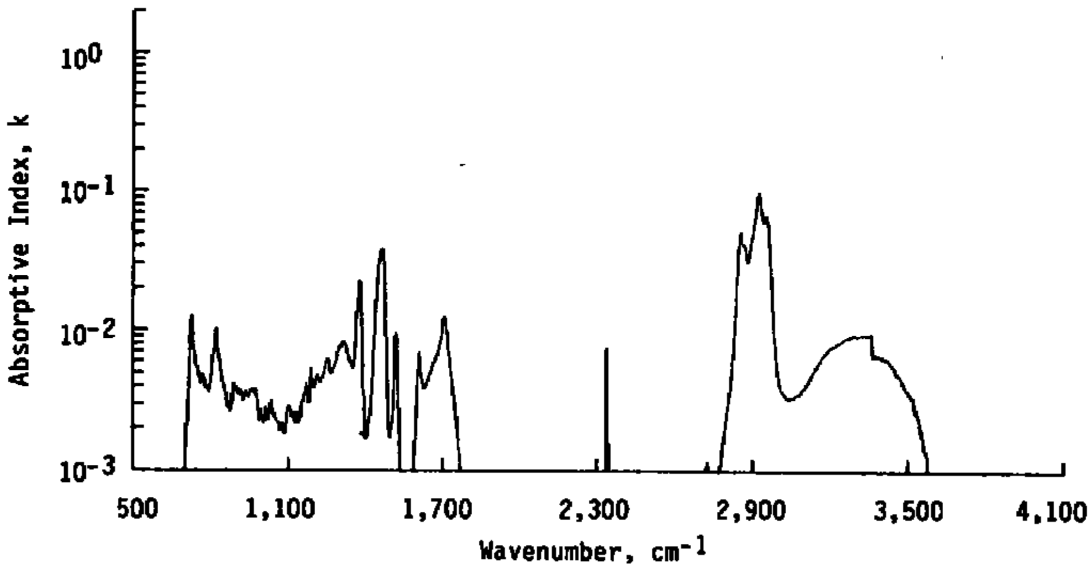




**Figure 34. Optical properties for Vac-Kote lubricating oil outgassing products.**

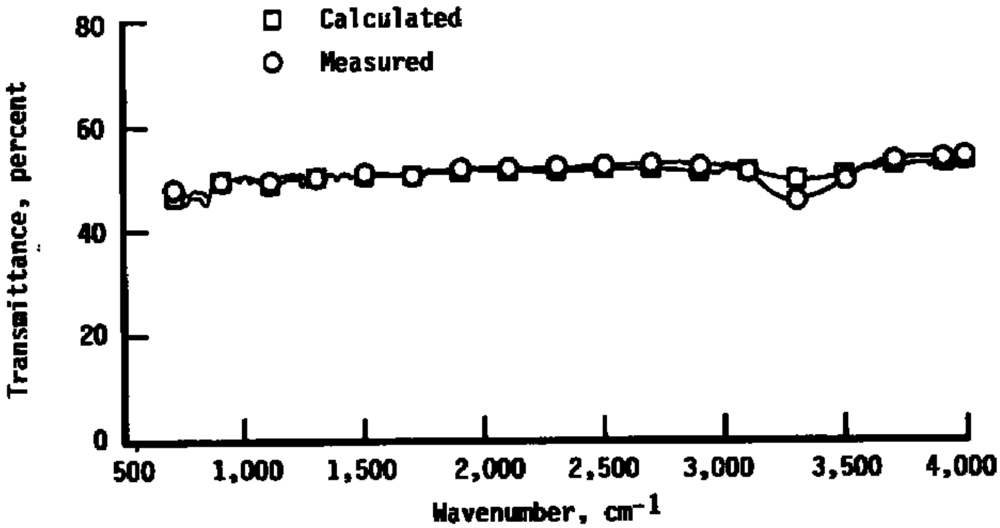



**Figure 35. Measured and calculated transmittance for a 0.23-μm thickness of Chemglaze Z306 black paint outgassing products.**

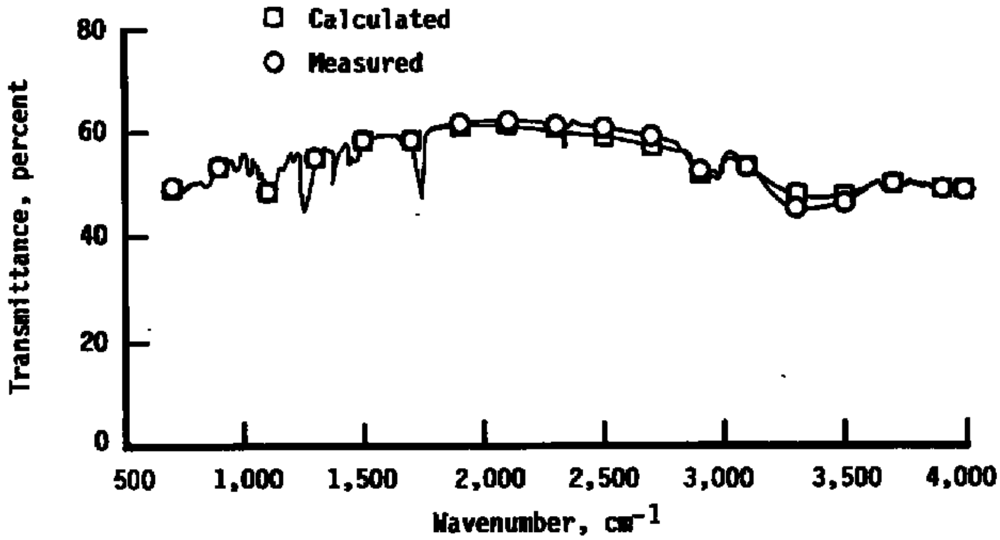



**Figure 36. Measured and calculated transmittance for a 0.91-μm thickness of Chemglaze Z306 black paint outgassing products.**

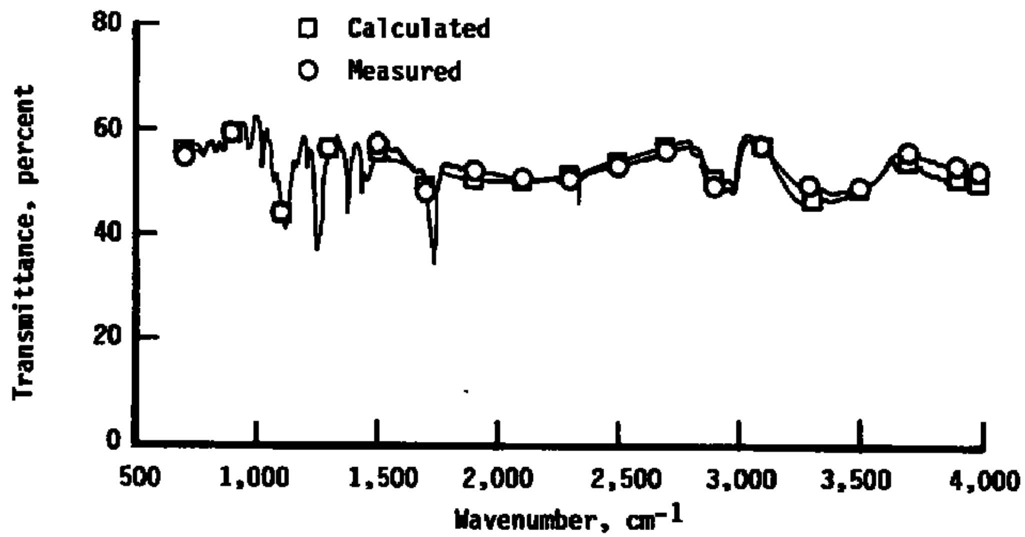



Figure 37. Measured and calculated transmittance for a 1.82-$\mu$m thickness of Chemglaze Z306 black paint outgassing products.

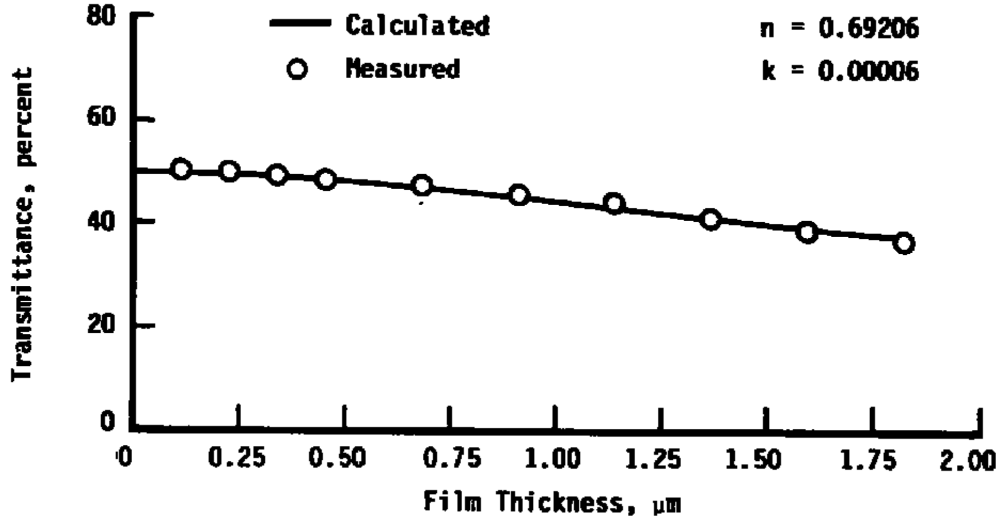



Figure 38. Measured and calculated transmittance at 1,250 $cm^{-1}$ for Chemglaze Z306 black paint outgassing products.

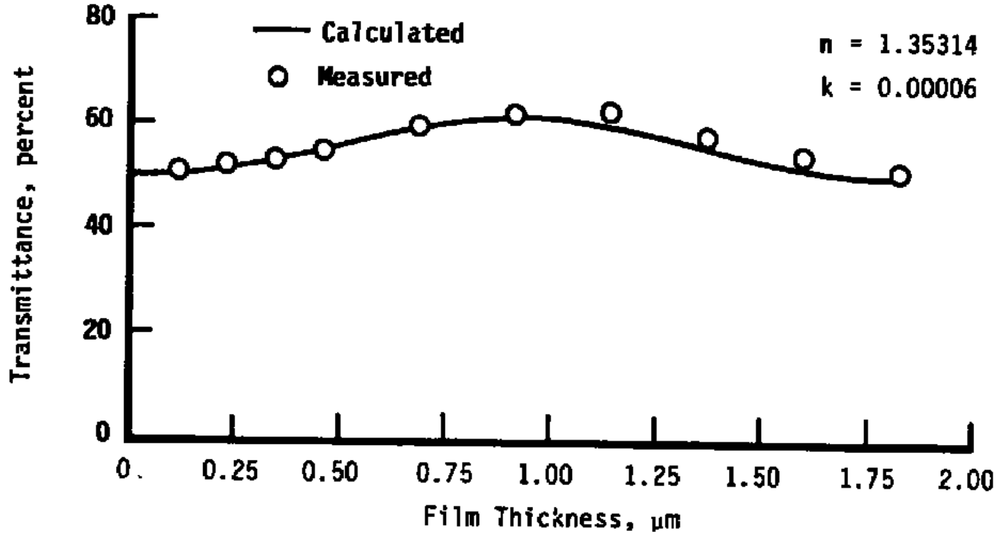



**Figure 39. Measured and calculated transmittance at 2,000 $cm^{-1}$ for Chemglaze Z306 black paint outgassing products.**

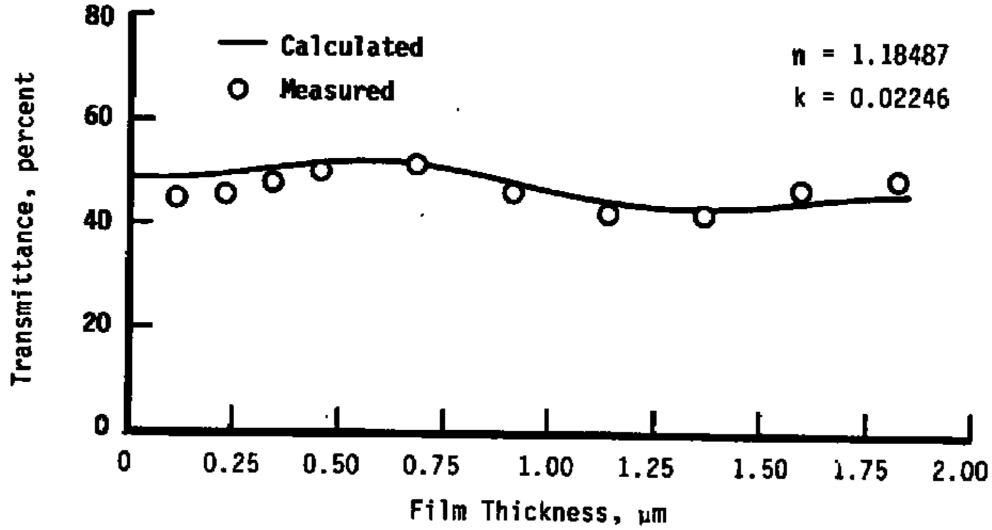



**Figure 40. Measured and calculated transmittance at 3,250 $cm^{-1}$ for Chemglaze Z306 black paint outgassing products.**

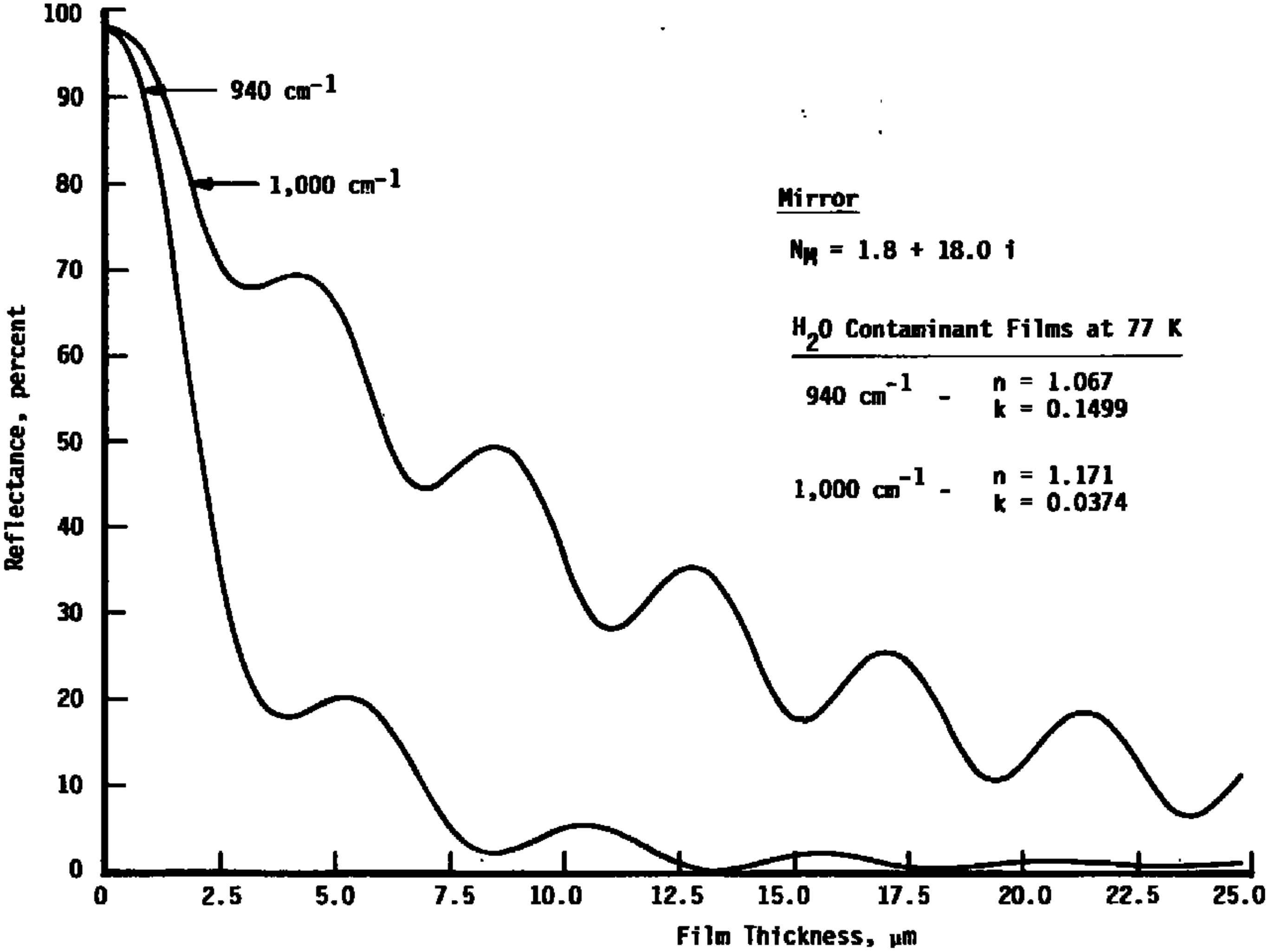



**Figure 41. Calculated effects of water contaminant films on a 77 K mirror for 1,000 $cm^{-1}$ (10.0 $\mu m$) and 940 $cm^{-1}$ (10.64 $\mu m$) using CALCRT.**

**Table 1. Materials List for Contamination Outgassing Kinetics and Surface Effects Studies**

**Adhesives**

1. DC93-500
2. DC6-1104
3. RTV566
4. RTV560
5. Solithane 113

**Films**

6. Kapton®
7. Mylar®
8. FEP Teflon®

**Fluids and Lubricants**

9. Braykote 8152 (Bray Oil Co.)
10. 40CS PAO-XRM-109 (Mobil)
11. Krytoc 143 AD (Dupont)
12. Braykote 600 Grease (Bray Oil Co.)

**Paints**

13. Chemglaze Z 306
14. Chemglaze A 237
15. Replacement for S-13GLO (Using V-10 Binder)
16. Replacement for S-13GLO (Using RTV-12 Binder)
17. Silver Flake/Silicon Silicate Thermal Control Developmental Coating

**Composites**

18. Polyimide Organic Matrix Composite
19. P75S Pitch 934 Graphite Epoxy
20. Graphite Epoxy Composite (HY-E1334A)

**Others**

21. Polyster Velcro®
22. Silicon Fluoride Rubber (Used to Make Electrical Connectors)
23. 966 Acrylic Transfer Tape Made by 3M
24. Dimethyl Silicone Elastomer
25. Shrink Tubing
26. PC Board

**Table 2. Materials Studies in AEDC 2- by 3-ft Cryogenic Optics Degradation Chamber**

| Material | Film Reference Index at 0.6328 $\mu$m | Film Density, gm/cc | Film Thickness, $\mu$m | Film IR n's k's yes, no | Sample Mass, gm | TML, percent | Material Type |
|---|---|---|---|---|---|---|---|
| Lockheed 0200 | 1.33 | 1.03 | 3.99 | Yes | $\approx$47 | --- | Paint |
| Lockheed 0200 (75°C) | 1.32 | 0.95 | 4.29 | Yes | 42.7083 | --- | Paint |
| Lockheed 0100 | 1.19 | 0.82 | 5.06 | Yes | 8.8237 | 5.95 | Paint |
| Lockheed 0300 | 1.37 | 0.94 | 2.77 | Yes | 28.3688 | 0.63 | Paint |
| Chemglaze Z306 | 1.45 | 1.03 | 1.82 | Yes | 6.7162 | 2.07 | Paint |
| Chemglaze A276 | 1.47 | 1.00 | 10.7 | Yes | 14.9695 | 4.80 | Paint |
| Solithane 113 | --- | --- | $\approx$0.85 | No | 38.5315 | 0.20 | Adhesive |
| Stycast 2850 | --- | --- | $\approx$0.37 | No | 113.4790 | 0.02 | Adhesive |
| Epoxi-patch | --- | --- | $\approx$0.25 | No | 89.6960 | 0.01 | Adhesive |
| Crest 7450 | 1.32 | 0.94 | 11.24 | Yes | 93.0990 | 0.35 | Adhesive |
| Mocap Tape | --- | --- | $\approx$0.13 | No | 1.1217 | 0.52 | Adhesive |
| Mylar | 1.28 | 1.07 | 1.25 | No | 123.0593 | 0.13 | Film |
| FEP Teflon | --- | --- | $\approx$0.25 | No | 142.7436 | 0.01 | Film |
| PEEK/AS4 | --- | --- | $\approx$0.25 | No | 82.9237 | 0.03 | Composite |
| J2/AS4 | 1.32 | 0.85 | 3.01 | No | 110.7016 | 0.03 | Composite |
| AS4/PPS | --- | --- | --- | No | 93.1507 | 0.03 | Composite |
| EP30LI (AS4/3501-6) | 1.32 | 0.75 | $\approx$1.5 | Yes | 102.1996 | 0.12 | Composite |
| AS4/3501 | 1.32 | 1.08 | 1.00 | No | 70.5290 | 0.23 | Composite |
| Braycote 600 | --- | --- | $\approx$0.3 | No | 24.4514 | 0.04 | Lubricant |
| Brayco 815Z | --- | --- | $\approx$0.12 | No | 23.4188 | 0.02 | Lubricant |
| Vac-Kote Oil | 1.39 | 0.66 | 11.38 | Yes | 25.6443 | 1.97 | Lubricant |

**Table 3. Optical Properties for Chemglaze Z306 Black Paint Outgassing Products Deposited at 77 K**

| $cm^{-1}$ | n | k | $cm^{-1}$ | n | k | $cm^{-1}$ | n | k |
|---|---|---|---|---|---|---|---|---|
| 700 | 1.43284 | 0.59062E-04 | 800 | 1.43110 | 0.59062E-04 | 900 | 1.40694 | 0.14978E-01 |
| 702 | 1.43387 | 0.59062E-04 | 802 | 1.42697 | 0.59062E-04 | 902 | 1.39492 | 0.13879E-01 |
| 704 | 1.43786 | 0.59062E-04 | 804 | 1.43280 | 0.59062E-04 | 904 | 1.40112 | 0.16444E-01 |
| 706 | 1.43706 | 0.59062E-04 | 806 | 1.42810 | 0.59062E-04 | 906 | 1.39047 | 0.15434E-01 |
| 708 | 1.44555 | 0.59062E-04 | 808 | 1.42734 | 0.59062E-04 | 908 | 1.39152 | 0.16516E-01 |
| 710 | 1.45005 | 0.59062E-04 | 810 | 1.43066 | 0.59062E-04 | 910 | 1.39702 | 0.16020E-01 |
| 712 | 1.44811 | 0.59062E-04 | 812 | 1.42324 | 0.59062E-04 | 912 | 1.39262 | 0.14446E-01 |
| 714 | 1.44879 | 0.59062E-04 | 814 | 1.41819 | 0.59062E-04 | 914 | 1.39694 | 0.12684E-01 |
| 716 | 1.45628 | 0.59062E-04 | 816 | 1.42077 | 0.59062E-04 | 916 | 1.39111 | 0.94929E-02 |
| 718 | 1.46061 | 0.59062E-04 | 818 | 1.42221 | 0.59062E-04 | 918 | 1.40173 | 0.98273E-02 |
| 720 | 1.46178 | 0.59062E-04 | 820 | 1.42460 | 0.59062E-04 | 920 | 1.39917 | 0.75159E-02 |
| 722 | 1.46828 | 0.59062E-04 | 822 | 1.42394 | 0.59062E-04 | 922 | 1.40098 | 0.74546E-02 |
| 724 | 1.47711 | 0.59062E-04 | 824 | 1.41184 | 0.59062E-04 | 924 | 1.40339 | 0.87481E-02 |
| 726 | 1.48175 | 0.59062E-04 | 826 | 1.39809 | 0.59062E-04 | 926 | 1.40689 | 0.11336E-01 |
| 728 | 1.48519 | 0.59062E-04 | 828 | 1.39473 | 0.59062E-04 | 928 | 1.40954 | 0.13170E-01 |
| 730 | 1.49670 | 0.59062E-04 | 830 | 1.40151 | 0.59062E-04 | 930 | 1.40882 | 0.13308E-01 |
| 732 | 1.49992 | 0.59062E-04 | 832 | 1.42763 | 0.59062E-04 | 932 | 1.40882 | 0.12269E-01 |
| 734 | 1.50749 | 0.59062E-04 | 834 | 1.45140 | 0.59062E-04 | 934 | 1.40898 | 0.10625E-01 |
| 736 | 1.51268 | 0.59062E-04 | 836 | 1.46617 | 0.59062E-04 | 936 | 1.40454 | 0.90917E-02 |
| 738 | 1.52289 | 0.59062E-04 | 838 | 1.47829 | 0.59062E-04 | 938 | 1.40769 | 0.79663E-02 |
| 740 | 1.53422 | 0.59062E-04 | 840 | 1.48221 | 0.59062E-04 | 940 | 1.40627 | 0.76223E-02 |
| 742 | 1.53299 | 0.59062E-04 | 842 | 1.47679 | 0.59062E-04 | 942 | 1.40508 | 0.68264E-02 |
| 744 | 1.53623 | 0.59062E-04 | 844 | 1.47382 | 0.59062E-04 | 944 | 1.41049 | 0.73068E-02 |
| 746 | 1.53604 | 0.59062E-04 | 846 | 1.46276 | 0.59062E-04 | 946 | 1.41147 | 0.67279E-02 |
| 748 | 1.53314 | 0.59062E-04 | 848 | 1.44142 | 0.59062E-04 | 948 | 1.41931 | 0.81600E-02 |
| 750 | 1.53078 | 0.59062E-04 | 850 | 1.42394 | 0.59062E-04 | 950 | 1.42434 | 0.10185E-01 |
| 752 | 1.52085 | 0.59062E-04 | 852 | 1.40279 | 0.36318E-03 | 952 | 1.42682 | 0.12532E-01 |
| 754 | 1.50180 | 0.59062E-04 | 854 | 1.41198 | 0.63177E-02 | 954 | 1.42422 | 0.15060E-01 |
| 756 | 1.49354 | 0.59062E-04 | 856 | 1.41681 | 0.10975E-01 | 956 | 1.43229 | 0.21941E-01 |
| 758 | 1.47579 | 0.59062E-04 | 858 | 1.41847 | 0.16401E-01 | 958 | 1.43202 | 0.28861E-01 |
| 760 | 1.46619 | 0.59062E-04 | 860 | 1.41850 | 0.22742E-01 | 960 | 1.41675 | 0.33420E-01 |
| 762 | 1.45650 | 0.59062E-04 | 862 | 1.42619 | 0.29799E-01 | 962 | 1.41100 | 0.37716E-01 |
| 764 | 1.44593 | 0.59062E-04 | 864 | 1.43555 | 0.32344E-01 | 964 | 1.41389 | 0.41366E-01 |
| 766 | 1.42666 | 0.59062E-04 | 866 | 1.42057 | 0.26830E-01 | 966 | 1.40786 | 0.41541E-01 |
| 768 | 1.40410 | 0.59062E-04 | 868 | 1.41442 | 0.21680E-01 | 968 | 1.39642 | 0.39896E-01 |
| 770 | 1.38384 | 0.59062E-04 | 870 | 1.40750 | 0.16658E-01 | 970 | 1.39617 | 0.37666E-01 |
| 772 | 1.37254 | 0.59062E-04 | 872 | 1.41002 | 0.14446E-01 | 972 | 1.38909 | 0.33121E-01 |
| 774 | 1.36221 | 0.59062E-04 | 874 | 1.40519 | 0.12070E-01 | 974 | 1.38365 | 0.28197E-01 |
| 776 | 1.36609 | 0.59062E-04 | 876 | 1.39949 | 0.10507E-01 | 976 | 1.38773 | 0.23245E-01 |
| 778 | 1.36129 | 0.59062E-04 | 878 | 1.40341 | 0.10967E-01 | 978 | 1.38828 | 0.16322E-01 |
| 780 | 1.37848 | 0.59062E-04 | 880 | 1.40735 | 0.11970E-01 | 980 | 1.39046 | 0.10562E-01 |
| 782 | 1.39571 | 0.59062E-04 | 882 | 1.40648 | 0.11204E-01 | 982 | 1.39254 | 0.47528E-02 |
| 784 | 1.40411 | 0.59062E-04 | 884 | 1.41066 | 0.12804E-01 | 984 | 1.39836 | 0.23555E-02 |
| 786 | 1.40702 | 0.59062E-04 | 886 | 1.41069 | 0.16107E-01 | 986 | 1.39780 | 0.89039E-03 |
| 788 | 1.41484 | 0.59062E-04 | 888 | 1.39805 | 0.16106E-01 | 988 | 1.40687 | 0.59062E-04 |
| 790 | 1.42062 | 0.59062E-04 | 890 | 1.39691 | 0.14621E-01 | 990 | 1.41628 | 0.59062E-04 |
| 792 | 1.42787 | 0.59062E-04 | 892 | 1.39503 | 0.15444E-01 | 992 | 1.42253 | 0.59062E-04 |
| 794 | 1.43120 | 0.59062E-04 | 894 | 1.39700 | 0.16037E-01 | 994 | 1.42348 | 0.59062E-04 |
| 796 | 1.42631 | 0.59062E-04 | 896 | 1.40080 | 0.15240E-01 | 996 | 1.42637 | 0.59062E-04 |
| 798 | 1.43021 | 0.59062E-04 | 898 | 1.40674 | 0.15375E-01 | 998 | 1.42913 | 0.59062E-04 |

## Table 3. Continued.

| $cm^{-1}$ | n | k | $cm^{-1}$ | n | k | $cm^{-1}$ | n | k |
|---|---|---|---|---|---|---|---|---|
| 1000 | 1.42514 | 0.90597E-03 | 1100 | 1.35728 | 0.11909E+00 | 1200 | 1.39044 | 0.25734E-01 |
| 1002 | 1.42669 | 0.25276E-02 | 1102 | 1.34232 | 0.12100E+00 | 1202 | 1.38813 | 0.32609E-01 |
| 1004 | 1.43026 | 0.44376E-02 | 1104 | 1.33492 | 0.12400E+00 | 1204 | 1.38432 | 0.39538E-01 |
| 1006 | 1.43094 | 0.65017E-02 | 1106 | 1.32108 | 0.12577E+00 | 1206 | 1.37594 | 0.42619E-01 |
| 1008 | 1.44251 | 0.11225E-01 | 1108 | 1.29786 | 0.12699E+00 | 1208 | 1.36825 | 0.40969E-01 |
| 1010 | 1.44646 | 0.17766E-01 | 1110 | 1.28053 | 0.12910E+00 | 1210 | 1.36412 | 0.36105E-01 |
| 1012 | 1.45165 | 0.27893E-01 | 1112 | 0.81234 | 0.55124E-02 | 1212 | 1.36569 | 0.29603E-01 |
| 1014 | 1.44278 | 0.39893E-01 | 1114 | 0.78849 | 0.52092E-04 | 1214 | 1.36962 | 0.23283E-01 |
| 1016 | 1.42278 | 0.51191E-01 | 1116 | 0.77982 | 0.59062E-04 | 1216 | 1.37921 | 0.20381E-01 |
| 1018 | 1.40624 | 0.59733E-01 | 1118 | 0.78019 | 0.59062E-04 | 1218 | 1.38636 | 0.20821E-01 |
| 1020 | 1.39796 | 0.63004E-01 | 1120 | 0.78808 | 0.59062E-04 | 1220 | 1.39150 | 0.21727E-01 |
| 1022 | 1.36967 | 0.57356E-01 | 1122 | 0.80603 | 0.59062E-04 | 1222 | 1.39334 | 0.21646E-01 |
| 1024 | 1.37398 | 0.52133E-01 | 1124 | 0.84302 | 0.59062E-04 | 1224 | 1.40094 | 0.22345E-01 |
| 1026 | 1.38054 | 0.46302E-01 | 1126 | 0.89129 | 0.59062E-04 | 1226 | 1.40803 | 0.23812E-01 |
| 1028 | 1.37830 | 0.37003E-01 | 1128 | 0.93201 | 0.59062E-04 | 1228 | 1.42062 | 0.27526E-01 |
| 1030 | 1.38148 | 0.28805E-01 | 1130 | 1.23218 | 0.72818E-01 | 1230 | 1.43457 | 0.35000E-01 |
| 1032 | 1.38374 | 0.20539E-01 | 1132 | 1.24615 | 0.66554E-01 | 1232 | 1.44622 | 0.47282E-01 |
| 1034 | 1.39341 | 0.14593E-01 | 1134 | 1.25964 | 0.61714E-01 | 1234 | 1.46216 | 0.65059E-01 |
| 1036 | 1.40199 | 0.10996E-01 | 1136 | 1.27436 | 0.57570E-01 | 1236 | 1.46738 | 0.86460E-01 |
| 1038 | 1.40405 | 0.10029E-01 | 1138 | 1.28072 | 0.51017E-01 | 1238 | 1.45619 | 0.10628E+00 |
| 1040 | 1.40380 | 0.10748E-01 | 1140 | 1.28827 | 0.43387E-01 | 1240 | 1.43363 | 0.12216E+00 |
| 1042 | 1.40506 | 0.13318E-01 | 1142 | 1.29855 | 0.38211E-01 | 1242 | 1.40264 | 0.13661E+00 |
| 1044 | 1.39538 | 0.16452E-01 | 1144 | 1.30548 | 0.35594E-01 | 1244 | 1.36194 | 0.14875E+00 |
| 1046 | 1.38513 | 0.20135E-01 | 1146 | 1.31506 | 0.35498E-01 | 1246 | 1.26808 | 0.15086E+00 |
| 1048 | 1.37579 | 0.22874E-01 | 1148 | 1.32118 | 0.36986E-01 | 1248 | 0.69638 | 0.79466E-04 |
| 1050 | 1.36704 | 0.23253E-01 | 1150 | 1.32465 | 0.39885E-01 | 1250 | 0.69206 | 0.59062E-04 |
| 1052 | 1.37426 | 0.23619E-01 | 1152 | 1.32039 | 0.41606E-01 | 1252 | 0.69964 | 0.59062E-04 |
| 1054 | 1.38568 | 0.24481E-01 | 1154 | 1.31931 | 0.43524E-01 | 1254 | 0.71580 | 0.59062E-04 |
| 1056 | 1.39612 | 0.28323E-01 | 1156 | 1.31549 | 0.43584E-01 | 1256 | 0.73997 | 0.59062E-04 |
| 1058 | 1.41276 | 0.35888E-01 | 1158 | 1.31914 | 0.42650E-01 | 1258 | 0.76401 | 0.59062E-04 |
| 1060 | 1.42727 | 0.46782E-01 | 1160 | 1.32208 | 0.41423E-01 | 1260 | 1.21546 | 0.12317E+00 |
| 1062 | 1.43123 | 0.58503E-01 | 1162 | 1.32266 | 0.40707E-01 | 1262 | 1.23744 | 0.12348E+00 |
| 1064 | 1.41831 | 0.68284E-01 | 1164 | 1.32159 | 0.38716E-01 | 1264 | 1.24826 | 0.11988E+00 |
| 1066 | 1.40061 | 0.73836E-01 | 1166 | 1.31680 | 0.35130E-01 | 1266 | 1.24346 | 0.11189E+00 |
| 1068 | 1.39460 | 0.76444E-01 | 1168 | 1.31744 | 0.30626E-01 | 1268 | 1.23631 | 0.10482E+00 |
| 1070 | 1.38675 | 0.74158E-01 | 1170 | 1.32172 | 0.27143E-01 | 1270 | 1.22788 | 0.96892E-01 |
| 1072 | 1.38454 | 0.69410E-01 | 1172 | 1.32432 | 0.24416E-01 | 1272 | 1.22801 | 0.86171E-01 |
| 1074 | 1.39154 | 0.65355E-01 | 1174 | 1.32300 | 0.21162E-01 | 1274 | 1.22454 | 0.73809E-01 |
| 1076 | 1.38828 | 0.61778E-01 | 1176 | 1.32935 | 0.18188E-01 | 1276 | 1.21907 | 0.62031E-01 |
| 1078 | 1.40020 | 0.63605E-01 | 1178 | 1.33418 | 0.15233E-01 | 1278 | 1.22084 | 0.51835E-01 |
| 1080 | 1.40343 | 0.66671E-01 | 1180 | 1.34161 | 0.12965E-01 | 1280 | 1.22508 | 0.43411E-01 |
| 1082 | 1.40092 | 0.72341E-01 | 1182 | 1.34674 | 0.11571E-01 | 1282 | 1.23029 | 0.36029E-01 |
| 1084 | 1.39552 | 0.78010E-01 | 1184 | 1.35144 | 0.10472E-01 | 1284 | 1.24238 | 0.30804E-01 |
| 1086 | 1.38796 | 0.82760E-01 | 1186 | 1.35816 | 0.10580E-01 | 1286 | 1.24649 | 0.25507E-01 |
| 1088 | 1.38193 | 0.87365E-01 | 1188 | 1.36476 | 0.11400E-01 | 1288 | 1.26017 | 0.21438E-01 |
| 1090 | 1.37662 | 0.92235E-01 | 1190 | 1.36927 | 0.11339E-01 | 1290 | 1.26070 | 0.18081E-01 |
| 1092 | 1.37288 | 0.97000E-01 | 1192 | 1.37249 | 0.11419E-01 | 1292 | 1.26665 | 0.16016E-01 |
| 1094 | 1.38015 | 0.10472E+00 | 1194 | 1.37473 | 0.11652E-01 | 1294 | 1.27009 | 0.13323E-01 |
| 1096 | 1.37073 | 0.10991E+00 | 1196 | 1.38352 | 0.14787E-01 | 1296 | 1.27486 | 0.11512E-01 |
| 1098 | 1.37368 | 0.11636E+00 | 1198 | 1.38548 | 0.19176E-01 | 1298 | 1.27820 | 0.10324E-01 |

## Table 3. Continued.

| $cm^{-1}$ | n | k | $cm^{-1}$ | n | k | $cm^{-1}$ | n | k |
|---|---|---|---|---|---|---|---|---|
| 1300 | 1.28135 | 0.97065E-02 | 1400 | 1.30309 | 0.30688E-02 | 1500 | 1.33339 | 0.59062E-04 |
| 1302 | 1.28613 | 0.90268E-02 | 1402 | 1.30255 | 0.14784E-02 | 1502 | 1.33872 | 0.59062E-04 |
| 1304 | 1.28763 | 0.81460E-02 | 1404 | 1.30401 | 0.28730E-03 | 1504 | 1.33552 | 0.59062E-04 |
| 1306 | 1.29205 | 0.76224E-02 | 1406 | 1.31488 | 0.86879E-04 | 1506 | 1.31047 | 0.59062E-04 |
| 1308 | 1.29356 | 0.66385E-02 | 1408 | 1.32024 | 0.59062E-04 | 1508 | 1.32574 | 0.59062E-04 |
| 1310 | 1.29325 | 0.58254E-02 | 1410 | 1.31752 | 0.59062E-04 | 1510 | 1.34586 | 0.59062E-04 |
| 1312 | 1.29516 | 0.47871E-02 | 1412 | 1.32868 | 0.59062E-04 | 1512 | 1.34736 | 0.59062E-04 |
| 1314 | 1.30228 | 0.34035E-02 | 1414 | 1.32604 | 0.59062E-04 | 1514 | 1.34239 | 0.59062E-04 |
| 1316 | 1.30005 | 0.33581E-02 | 1416 | 1.32544 | 0.18638E-03 | 1516 | 1.34394 | 0.59062E-04 |
| 1318 | 1.29595 | 0.20415E-02 | 1418 | 1.32278 | 0.23147E-02 | 1518 | 1.33787 | 0.59062E-04 |
| 1320 | 1.29607 | 0.59799E-03 | 1420 | 1.32485 | 0.46479E-02 | 1520 | 1.34200 | 0.59062E-04 |
| 1322 | 1.30098 | 0.17163E-03 | 1422 | 1.33079 | 0.66102E-02 | 1522 | 1.34162 | 0.59062E-04 |
| 1324 | 1.30715 | 0.86500E-04 | 1424 | 1.33623 | 0.12165E-01 | 1524 | 1.34530 | 0.59062E-04 |
| 1326 | 1.31474 | 0.59062E-04 | 1426 | 1.34229 | 0.17086E-01 | 1526 | 1.35202 | 0.59062E-04 |
| 1328 | 1.32081 | 0.59062E-04 | 1428 | 1.34359 | 0.24509E-01 | 1528 | 1.35003 | 0.59062E-04 |
| 1330 | 1.32349 | 0.59062E-04 | 1430 | 1.35023 | 0.38990E-01 | 1530 | 1.35095 | 0.59062E-04 |
| 1332 | 1.32808 | 0.59062E-04 | 1432 | 1.34925 | 0.50123E-01 | 1532 | 1.34626 | 0.59062E-04 |
| 1334 | 1.32592 | 0.59062E-04 | 1434 | 1.32669 | 0.49441E-01 | 1534 | 1.34677 | 0.59062E-04 |
| 1336 | 1.32930 | 0.59062E-04 | 1436 | 1.31604 | 0.39134E-01 | 1536 | 1.35120 | 0.59062E-04 |
| 1338 | 1.31176 | 0.69434E-03 | 1438 | 1.31420 | 0.30312E-01 | 1538 | 1.34297 | 0.59062E-04 |
| 1340 | 1.32312 | 0.50254E-03 | 1440 | 1.31683 | 0.28506E-01 | 1540 | 1.33022 | 0.59062E-04 |
| 1342 | 1.32560 | 0.25847E-02 | 1442 | 1.31946 | 0.29058E-01 | 1542 | 1.35251 | 0.59062E-04 |
| 1344 | 1.32956 | 0.44808E-02 | 1444 | 1.31798 | 0.30788E-01 | 1544 | 1.35705 | 0.59062E-04 |
| 1346 | 1.32847 | 0.58231E-02 | 1446 | 1.31491 | 0.32111E-01 | 1546 | 1.35530 | 0.59062E-04 |
| 1348 | 1.32987 | 0.69210E-02 | 1448 | 1.30977 | 0.31711E-01 | 1548 | 1.35247 | 0.59062E-04 |
| 1350 | 1.33164 | 0.83580E-02 | 1450 | 1.30969 | 0.31864E-01 | 1550 | 1.34976 | 0.59062E-04 |
| 1352 | 1.33794 | 0.10863E-01 | 1452 | 1.30928 | 0.30782E-01 | 1552 | 1.35120 | 0.59062E-04 |
| 1354 | 1.33898 | 0.13137E-01 | 1454 | 1.30320 | 0.31218E-01 | 1554 | 1.34885 | 0.59062E-04 |
| 1356 | 1.34006 | 0.14607E-01 | 1456 | 1.30028 | 0.29979E-01 | 1556 | 1.34718 | 0.59062E-04 |
| 1358 | 1.34173 | 0.14142E-01 | 1458 | 1.31036 | 0.28988E-01 | 1558 | 1.34317 | 0.59062E-04 |
| 1360 | 1.34747 | 0.16970E-01 | 1460 | 1.30390 | 0.28184E-01 | 1560 | 1.36707 | 0.59062E-04 |
| 1362 | 1.35014 | 0.19364E-01 | 1462 | 1.30143 | 0.27368E-01 | 1562 | 1.36000 | 0.59062E-04 |
| 1364 | 1.35581 | 0.25375E-01 | 1464 | 1.29270 | 0.25328E-01 | 1564 | 1.35791 | 0.59062E-04 |
| 1366 | 1.36222 | 0.35037E-01 | 1466 | 1.29283 | 0.22476E-01 | 1566 | 1.35634 | 0.59062E-04 |
| 1368 | 1.36011 | 0.50092E-01 | 1468 | 1.29657 | 0.20506E-01 | 1568 | 1.35517 | 0.59062E-04 |
| 1370 | 1.34907 | 0.68086E-01 | 1470 | 1.29075 | 0.18504E-01 | 1570 | 1.35384 | 0.59062E-04 |
| 1372 | 1.33177 | 0.81084E-01 | 1472 | 1.27968 | 0.16223E-01 | 1572 | 1.35649 | 0.59062E-04 |
| 1374 | 1.29637 | 0.82198E-01 | 1474 | 1.28663 | 0.13410E-01 | 1574 | 1.35660 | 0.59062E-04 |
| 1376 | 1.28041 | 0.78549E-01 | 1476 | 1.29630 | 0.10941E-01 | 1576 | 1.35429 | 0.59062E-04 |
| 1378 | 1.26069 | 0.69529E-01 | 1478 | 1.29539 | 0.91517E-02 | 1578 | 1.35692 | 0.59062E-04 |
| 1380 | 1.25992 | 0.54062E-01 | 1480 | 1.29543 | 0.77448E-02 | 1580 | 1.35775 | 0.59062E-04 |
| 1382 | 1.25859 | 0.41972E-01 | 1482 | 1.29697 | 0.68938E-02 | 1582 | 1.35504 | 0.59062E-04 |
| 1384 | 1.26313 | 0.30689E-01 | 1484 | 1.30163 | 0.68857E-02 | 1584 | 1.35339 | 0.59062E-04 |
| 1386 | 1.27461 | 0.23844E-01 | 1486 | 1.29484 | 0.77309E-02 | 1586 | 1.35193 | 0.59062E-04 |
| 1388 | 1.28384 | 0.21015E-01 | 1488 | 1.29636 | 0.65494E-02 | 1588 | 1.35217 | 0.59062E-04 |
| 1390 | 1.28767 | 0.17288E-01 | 1490 | 1.28937 | 0.40994E-02 | 1590 | 1.35049 | 0.59062E-04 |
| 1392 | 1.28489 | 0.11330E-01 | 1492 | 1.29871 | 0.77479E-04 | 1592 | 1.34943 | 0.59062E-04 |
| 1394 | 1.28282 | 0.68831E-02 | 1494 | 1.31275 | 0.59062E-04 | 1594 | 1.35560 | 0.59062E-04 |
| 1396 | 1.29061 | 0.45967E-02 | 1496 | 1.31863 | 0.59062E-04 | 1596 | 1.35384 | 0.59062E-04 |
| 1398 | 1.29400 | 0.36357E-02 | 1498 | 1.32811 | 0.59062E-04 | 1598 | 1.34969 | 0.59062E-04 |

## Table 3. Continued.

| $cm^{-1}$ | n | k | $cm^{-1}$ | n | k | $cm^{-1}$ | n | k |
|---|---|---|---|---|---|---|---|---|
| 1600 | 1.34779 | 0.59062E-04 | 1700 | 1.35594 | 0.18593E-01 | 1800 | 1.33669 | 0.59062E-04 |
| 1602 | 1.34546 | 0.59062E-04 | 1702 | 1.35151 | 0.22526E-01 | 1802 | 1.33711 | 0.59062E-04 |
| 1604 | 1.34839 | 0.59062E-04 | 1704 | 1.35199 | 0.27078E-01 | 1804 | 1.33877 | 0.59062E-04 |
| 1606 | 1.34832 | 0.59062E-04 | 1706 | 1.35052 | 0.34387E-01 | 1806 | 1.33996 | 0.59062E-04 |
| 1608 | 1.34889 | 0.59062E-04 | 1708 | 1.35042 | 0.40142E-01 | 1808 | 1.33989 | 0.59062E-04 |
| 1610 | 1.34768 | 0.59062E-04 | 1710 | 1.34936 | 0.45320E-01 | 1810 | 1.33955 | 0.59062E-04 |
| 1612 | 1.34799 | 0.59062E-04 | 1712 | 1.34427 | 0.50760E-01 | 1812 | 1.34008 | 0.59062E-04 |
| 1614 | 1.34616 | 0.59062E-04 | 1714 | 1.34289 | 0.56119E-01 | 1814 | 1.34301 | 0.59062E-04 |
| 1616 | 1.34239 | 0.59062E-04 | 1716 | 1.34677 | 0.61378E-01 | 1816 | 1.34267 | 0.59062E-04 |
| 1618 | 1.34267 | 0.59062E-04 | 1718 | 1.34758 | 0.64671E-01 | 1818 | 1.34181 | 0.59062E-04 |
| 1620 | 1.34763 | 0.59062E-04 | 1720 | 1.35864 | 0.70208E-01 | 1820 | 1.34269 | 0.59062E-04 |
| 1622 | 1.34381 | 0.59062E-04 | 1722 | 1.35773 | 0.74459E-01 | 1822 | 1.34410 | 0.59062E-04 |
| 1624 | 1.34397 | 0.59062E-04 | 1724 | 1.36125 | 0.80592E-01 | 1824 | 1.34219 | 0.59062E-04 |
| 1626 | 1.34499 | 0.59062E-04 | 1726 | 1.36230 | 0.88374E-01 | 1826 | 1.34277 | 0.59062E-04 |
| 1628 | 1.34469 | 0.59062E-04 | 1728 | 1.35985 | 0.97314E-01 | 1828 | 1.34286 | 0.59062E-04 |
| 1630 | 1.34383 | 0.59062E-04 | 1730 | 1.35794 | 0.10297E+00 | 1830 | 1.34382 | 0.59062E-04 |
| 1632 | 1.34289 | 0.59062E-04 | 1732 | 1.35328 | 0.10961E+00 | 1832 | 1.34561 | 0.59062E-04 |
| 1634 | 1.34325 | 0.59062E-04 | 1734 | 1.32663 | 0.10403E+00 | 1834 | 1.34662 | 0.59062E-04 |
| 1636 | 1.33886 | 0.59062E-04 | 1736 | 1.31509 | 0.10722E+00 | 1836 | 1.34620 | 0.59062E-04 |
| 1638 | 1.34166 | 0.59062E-04 | 1738 | 1.29699 | 0.98035E-01 | 1838 | 1.34537 | 0.59062E-04 |
| 1640 | 1.34293 | 0.59062E-04 | 1740 | 1.27758 | 0.79758E-01 | 1840 | 1.34450 | 0.59062E-04 |
| 1642 | 1.33932 | 0.59062E-04 | 1742 | 1.26186 | 0.63612E-01 | 1842 | 1.34383 | 0.59062E-04 |
| 1644 | 1.33372 | 0.59062E-04 | 1744 | 1.25501 | 0.44982E-01 | 1844 | 1.34729 | 0.59062E-04 |
| 1646 | 1.32501 | 0.93958E-03 | 1746 | 1.25454 | 0.30162E-01 | 1846 | 1.34664 | 0.59062E-04 |
| 1648 | 1.33662 | 0.71032E-04 | 1748 | 1.25261 | 0.18116E-01 | 1848 | 1.34748 | 0.59062E-04 |
| 1650 | 1.33565 | 0.33318E-03 | 1750 | 1.26290 | 0.87433E-02 | 1850 | 1.34669 | 0.59062E-04 |
| 1652 | 1.33502 | 0.14905E-02 | 1752 | 1.27141 | 0.14030E-02 | 1852 | 1.34572 | 0.59062E-04 |
| 1654 | 1.36217 | 0.56340E-04 | 1754 | 1.28272 | 0.53034E-04 | 1854 | 1.34586 | 0.59062E-04 |
| 1656 | 1.34368 | 0.59062E-04 | 1756 | 1.28887 | 0.59062E-04 | 1856 | 1.34647 | 0.59062E-04 |
| 1658 | 1.33957 | 0.59062E-04 | 1758 | 1.29665 | 0.59062E-04 | 1858 | 1.34483 | 0.59062E-04 |
| 1660 | 1.33675 | 0.44671E-03 | 1760 | 1.30507 | 0.59062E-04 | 1860 | 1.34610 | 0.59062E-04 |
| 1662 | 1.33806 | 0.67858E-03 | 1762 | 1.30950 | 0.59062E-04 | 1862 | 1.34603 | 0.59062E-04 |
| 1664 | 1.33141 | 0.78506E-03 | 1764 | 1.31422 | 0.59062E-04 | 1864 | 1.34565 | 0.59062E-04 |
| 1666 | 1.33235 | 0.76482E-03 | 1766 | 1.31749 | 0.59062E-04 | 1866 | 1.34478 | 0.59062E-04 |
| 1668 | 1.33144 | 0.11501E-02 | 1768 | 1.31779 | 0.59062E-04 | 1868 | 1.34446 | 0.59062E-04 |
| 1670 | 1.32744 | 0.17395E-02 | 1770 | 1.31965 | 0.59062E-04 | 1870 | 1.34715 | 0.59062E-04 |
| 1672 | 1.33302 | 0.17500E-02 | 1772 | 1.32179 | 0.59062E-04 | 1872 | 1.34816 | 0.59062E-04 |
| 1674 | 1.33484 | 0.94738E-04 | 1774 | 1.32598 | 0.59062E-04 | 1874 | 1.34790 | 0.59062E-04 |
| 1676 | 1.33304 | 0.59062E-04 | 1776 | 1.32810 | 0.59062E-04 | 1876 | 1.34702 | 0.59062E-04 |
| 1678 | 1.33524 | 0.59062E-04 | 1778 | 1.32998 | 0.59062E-04 | 1878 | 1.34732 | 0.59062E-04 |
| 1680 | 1.33528 | 0.59062E-04 | 1780 | 1.32936 | 0.59062E-04 | 1880 | 1.34761 | 0.59062E-04 |
| 1682 | 1.34054 | 0.59062E-04 | 1782 | 1.33141 | 0.59062E-04 | 1882 | 1.34742 | 0.59062E-04 |
| 1684 | 1.34411 | 0.11104E-03 | 1784 | 1.33242 | 0.59062E-04 | 1884 | 1.34714 | 0.59062E-04 |
| 1686 | 1.34642 | 0.33412E-03 | 1786 | 1.33194 | 0.59062E-04 | 1886 | 1.34816 | 0.59062E-04 |
| 1688 | 1.34961 | 0.65041E-03 | 1788 | 1.33218 | 0.59062E-04 | 1888 | 1.34890 | 0.59062E-04 |
| 1690 | 1.34698 | 0.24071E-02 | 1790 | 1.33146 | 0.59062E-04 | 1890 | 1.34671 | 0.59062E-04 |
| 1692 | 1.34597 | 0.33381E-02 | 1792 | 1.33100 | 0.59062E-04 | 1892 | 1.34833 | 0.59062E-04 |
| 1694 | 1.34611 | 0.57178E-02 | 1794 | 1.33504 | 0.59062E-04 | 1894 | 1.34816 | 0.59062E-04 |
| 1696 | 1.34510 | 0.97992E-02 | 1796 | 1.33903 | 0.59062E-04 | 1896 | 1.34864 | 0.59062E-04 |
| 1698 | 1.35420 | 0.11525E-01 | 1798 | 1.33769 | 0.59062E-04 | 1898 | 1.34830 | 0.59062E-04 |

**Table 3. Continued.**

| cm⁻¹ | n | k | cm⁻¹ | n | k | cm⁻¹ | n | k |
|---|---|---|---|---|---|---|---|---|
| 1900 | 1.34822 | 0.59062E-04 | 2000 | 1.35314 | 0.59062E-04 | 2100 | 1.35098 | 0.59062E-04 |
| 1902 | 1.34805 | 0.59062E-04 | 2002 | 1.35362 | 0.59062E-04 | 2102 | 1.35097 | 0.59062E-04 |
| 1904 | 1.34733 | 0.59062E-04 | 2004 | 1.35247 | 0.59062E-04 | 2104 | 1.35176 | 0.59062E-04 |
| 1906 | 1.34852 | 0.59062E-04 | 2006 | 1.35305 | 0.59062E-04 | 2106 | 1.35191 | 0.59062E-04 |
| 1908 | 1.34884 | 0.59062E-04 | 2008 | 1.35365 | 0.59062E-04 | 2108 | 1.35139 | 0.59062E-04 |
| 1910 | 1.34937 | 0.59062E-04 | 2010 | 1.35314 | 0.59062E-04 | 2110 | 1.35178 | 0.59062E-04 |
| 1912 | 1.34909 | 0.59062E-04 | 2012 | 1.35231 | 0.59062E-04 | 2112 | 1.35063 | 0.59062E-04 |
| 1914 | 1.34798 | 0.59062E-04 | 2014 | 1.35243 | 0.59062E-04 | 2114 | 1.35050 | 0.59062E-04 |
| 1916 | 1.34864 | 0.59062E-04 | 2016 | 1.35181 | 0.59062E-04 | 2116 | 1.35122 | 0.59062E-04 |
| 1918 | 1.34864 | 0.59062E-04 | 2018 | 1.35292 | 0.59062E-04 | 2118 | 1.35130 | 0.59062E-04 |
| 1920 | 1.35003 | 0.59062E-04 | 2020 | 1.35240 | 0.59062E-04 | 2120 | 1.35116 | 0.59062E-04 |
| 1922 | 1.34824 | 0.59062E-04 | 2022 | 1.35434 | 0.59062E-04 | 2122 | 1.35205 | 0.59062E-04 |
| 1924 | 1.34872 | 0.59062E-04 | 2024 | 1.35377 | 0.59062E-04 | 2124 | 1.35155 | 0.59062E-04 |
| 1926 | 1.34984 | 0.59062E-04 | 2026 | 1.35400 | 0.59062E-04 | 2126 | 1.35055 | 0.59062E-04 |
| 1928 | 1.34928 | 0.59062E-04 | 2028 | 1.35445 | 0.59062E-04 | 2128 | 1.35013 | 0.59062E-04 |
| 1930 | 1.34894 | 0.59062E-04 | 2030 | 1.35449 | 0.59062E-04 | 2130 | 1.35073 | 0.59062E-04 |
| 1932 | 1.34922 | 0.59062E-04 | 2032 | 1.35394 | 0.59062E-04 | 2132 | 1.35110 | 0.59062E-04 |
| 1934 | 1.34932 | 0.59062E-04 | 2034 | 1.35398 | 0.59062E-04 | 2134 | 1.35214 | 0.59062E-04 |
| 1936 | 1.35081 | 0.59062E-04 | 2036 | 1.35350 | 0.59062E-04 | 2136 | 1.35111 | 0.59062E-04 |
| 1938 | 1.34977 | 0.59062E-04 | 2038 | 1.35335 | 0.59062E-04 | 2138 | 1.34982 | 0.59062E-04 |
| 1940 | 1.34995 | 0.59062E-04 | 2040 | 1.35347 | 0.59062E-04 | 2140 | 1.34891 | 0.59062E-04 |
| 1942 | 1.34976 | 0.59062E-04 | 2042 | 1.35418 | 0.59062E-04 | 2142 | 1.34906 | 0.59062E-04 |
| 1944 | 1.35075 | 0.59062E-04 | 2044 | 1.35499 | 0.59062E-04 | 2144 | 1.34873 | 0.59062E-04 |
| 1946 | 1.35034 | 0.59062E-04 | 2046 | 1.35490 | 0.59062E-04 | 2146 | 1.34892 | 0.59062E-04 |
| 1948 | 1.35101 | 0.59062E-04 | 2048 | 1.35424 | 0.59062E-04 | 2148 | 1.34975 | 0.59062E-04 |
| 1950 | 1.35057 | 0.59062E-04 | 2050 | 1.35292 | 0.59062E-04 | 2150 | 1.34884 | 0.59062E-04 |
| 1952 | 1.34997 | 0.59062E-04 | 2052 | 1.35260 | 0.59062E-04 | 2152 | 1.34990 | 0.59062E-04 |
| 1954 | 1.34990 | 0.59062E-04 | 2054 | 1.35378 | 0.59062E-04 | 2154 | 1.34992 | 0.59062E-04 |
| 1956 | 1.35000 | 0.59062E-04 | 2056 | 1.35355 | 0.59062E-04 | 2156 | 1.35043 | 0.59062E-04 |
| 1958 | 1.34994 | 0.59062E-04 | 2058 | 1.35395 | 0.59062E-04 | 2158 | 1.35061 | 0.59062E-04 |
| 1960 | 1.35100 | 0.59062E-04 | 2060 | 1.35361 | 0.59062E-04 | 2160 | 1.34961 | 0.59062E-04 |
| 1962 | 1.35130 | 0.59062E-04 | 2062 | 1.35294 | 0.59062E-04 | 2162 | 1.34901 | 0.59062E-04 |
| 1964 | 1.35136 | 0.59062E-04 | 2064 | 1.35292 | 0.59062E-04 | 2164 | 1.34966 | 0.59062E-04 |
| 1966 | 1.35088 | 0.59062E-04 | 2066 | 1.35330 | 0.59062E-04 | 2166 | 1.34923 | 0.59062E-04 |
| 1968 | 1.35127 | 0.59062E-04 | 2068 | 1.35377 | 0.59062E-04 | 2168 | 1.34913 | 0.59062E-04 |
| 1970 | 1.35136 | 0.59062E-04 | 2070 | 1.35240 | 0.59062E-04 | 2170 | 1.35003 | 0.59062E-04 |
| 1972 | 1.35229 | 0.59062E-04 | 2072 | 1.35270 | 0.59062E-04 | 2172 | 1.34903 | 0.59062E-04 |
| 1974 | 1.35133 | 0.59062E-04 | 2074 | 1.35186 | 0.59062E-04 | 2174 | 1.34871 | 0.59062E-04 |
| 1976 | 1.35128 | 0.59062E-04 | 2076 | 1.35271 | 0.59062E-04 | 2176 | 1.34856 | 0.59062E-04 |
| 1978 | 1.35212 | 0.59062E-04 | 2078 | 1.35220 | 0.59062E-04 | 2178 | 1.34692 | 0.59062E-04 |
| 1980 | 1.35230 | 0.59062E-04 | 2080 | 1.35166 | 0.59062E-04 | 2180 | 1.34780 | 0.59062E-04 |
| 1982 | 1.35246 | 0.59062E-04 | 2082 | 1.35294 | 0.59062E-04 | 2182 | 1.34789 | 0.59062E-04 |
| 1984 | 1.35262 | 0.59062E-04 | 2084 | 1.35099 | 0.59062E-04 | 2184 | 1.34752 | 0.59062E-04 |
| 1986 | 1.35155 | 0.59062E-04 | 2086 | 1.35184 | 0.59062E-04 | 2186 | 1.34831 | 0.59062E-04 |
| 1988 | 1.35151 | 0.59062E-04 | 2088 | 1.35158 | 0.59062E-04 | 2188 | 1.34801 | 0.59062E-04 |
| 1990 | 1.35139 | 0.59062E-04 | 2090 | 1.35179 | 0.59062E-04 | 2190 | 1.34808 | 0.59062E-04 |
| 1992 | 1.35420 | 0.59062E-04 | 2092 | 1.35226 | 0.59062E-04 | 2192 | 1.34797 | 0.59062E-04 |
| 1994 | 1.35379 | 0.59062E-04 | 2094 | 1.35187 | 0.59062E-04 | 2194 | 1.34748 | 0.59062E-04 |
| 1996 | 1.35269 | 0.59062E-04 | 2096 | 1.35121 | 0.59062E-04 | 2196 | 1.34751 | 0.59062E-04 |
| 1998 | 1.35314 | 0.59062E-04 | 2098 | 1.35195 | 0.59062E-04 | 2198 | 1.34683 | 0.59062E-04 |

## Table 3. Continued.

| $cm^{-1}$ | n | k | $cm^{-1}$ | n | k | $cm^{-1}$ | n | k |
|---|---|---|---|---|---|---|---|---|
| 2200 | 1.34694 | 0.59062E-04 | 2300 | 1.34669 | 0.59062E-04 | 2400 | 1.34223 | 0.59062E-04 |
| 2202 | 1.34740 | 0.59062E-04 | 2302 | 1.34904 | 0.59062E-04 | 2402 | 1.34154 | 0.59062E-04 |
| 2204 | 1.34787 | 0.59062E-04 | 2304 | 1.35018 | 0.59062E-04 | 2404 | 1.34301 | 0.59062E-04 |
| 2206 | 1.34829 | 0.59062E-04 | 2306 | 1.35141 | 0.59062E-04 | 2406 | 1.34139 | 0.59062E-04 |
| 2208 | 1.34736 | 0.59062E-04 | 2308 | 1.34972 | 0.59062E-04 | 2408 | 1.34222 | 0.59062E-04 |
| 2210 | 1.34760 | 0.59062E-04 | 2310 | 1.34714 | 0.59062E-04 | 2410 | 1.34396 | 0.59062E-04 |
| 2212 | 1.34739 | 0.59062E-04 | 2312 | 1.35058 | 0.59062E-04 | 2412 | 1.34350 | 0.59062E-04 |
| 2214 | 1.34695 | 0.59062E-04 | 2314 | 1.35458 | 0.59062E-04 | 2414 | 1.34228 | 0.59062E-04 |
| 2216 | 1.34635 | 0.59062E-04 | 2316 | 1.35052 | 0.59062E-04 | 2416 | 1.34331 | 0.59062E-04 |
| 2218 | 1.34689 | 0.59062E-04 | 2318 | 1.35355 | 0.59062E-04 | 2418 | 1.34232 | 0.59062E-04 |
| 2220 | 1.34758 | 0.59062E-04 | 2320 | 1.35166 | 0.59062E-04 | 2420 | 1.34229 | 0.59062E-04 |
| 2222 | 1.34858 | 0.59062E-04 | 2322 | 1.35109 | 0.59062E-04 | 2422 | 1.34263 | 0.59062E-04 |
| 2224 | 1.34834 | 0.59062E-04 | 2324 | 1.35492 | 0.59062E-04 | 2424 | 1.34307 | 0.59062E-04 |
| 2226 | 1.34738 | 0.59062E-04 | 2326 | 1.35785 | 0.59062E-04 | 2426 | 1.34213 | 0.59062E-04 |
| 2228 | 1.34904 | 0.59062E-04 | 2328 | 1.35651 | 0.59062E-04 | 2428 | 1.34218 | 0.59062E-04 |
| 2230 | 1.34848 | 0.59062E-04 | 2330 | 1.35565 | 0.59062E-04 | 2430 | 1.34321 | 0.59062E-04 |
| 2232 | 1.34739 | 0.59062E-04 | 2332 | 1.35043 | 0.59062E-04 | 2432 | 1.34597 | 0.59062E-04 |
| 2234 | 1.34778 | 0.59062E-04 | 2334 | 1.34126 | 0.59062E-04 | 2434 | 1.34445 | 0.59062E-04 |
| 2236 | 1.34784 | 0.59062E-04 | 2336 | 1.32767 | 0.56404E-02 | 2436 | 1.34342 | 0.59062E-04 |
| 2238 | 1.34766 | 0.59062E-04 | 2338 | 1.31864 | 0.12937E-01 | 2438 | 1.34284 | 0.59062E-04 |
| 2240 | 1.34821 | 0.59062E-04 | 2340 | 1.30590 | 0.12690E-01 | 2440 | 1.34313 | 0.59062E-04 |
| 2242 | 1.34826 | 0.59062E-04 | 2342 | 1.30250 | 0.35329E-02 | 2442 | 1.34124 | 0.59062E-04 |
| 2244 | 1.34805 | 0.59062E-04 | 2344 | 1.32418 | 0.66771E-04 | 2444 | 1.34291 | 0.59062E-04 |
| 2246 | 1.34718 | 0.59062E-04 | 2346 | 1.33703 | 0.59062E-04 | 2446 | 1.34292 | 0.59062E-04 |
| 2248 | 1.34519 | 0.59062E-04 | 2348 | 1.34398 | 0.59062E-04 | 2448 | 1.34388 | 0.59062E-04 |
| 2250 | 1.34510 | 0.59062E-04 | 2350 | 1.34193 | 0.59062E-04 | 2450 | 1.34410 | 0.59062E-04 |
| 2252 | 1.34525 | 0.59062E-04 | 2352 | 1.34565 | 0.59062E-04 | 2452 | 1.34521 | 0.59062E-04 |
| 2254 | 1.34126 | 0.59062E-04 | 2354 | 1.34369 | 0.59062E-04 | 2454 | 1.34505 | 0.59062E-04 |
| 2256 | 1.34245 | 0.59062E-04 | 2356 | 1.34340 | 0.59062E-04 | 2456 | 1.34178 | 0.59062E-04 |
| 2258 | 1.34195 | 0.59062E-04 | 2358 | 1.33847 | 0.59062E-04 | 2458 | 1.34320 | 0.59062E-04 |
| 2260 | 1.34085 | 0.59062E-04 | 2360 | 1.33864 | 0.59062E-04 | 2460 | 1.34384 | 0.59062E-04 |
| 2262 | 1.33858 | 0.59062E-04 | 2362 | 1.34266 | 0.59062E-04 | 2462 | 1.34454 | 0.59062E-04 |
| 2264 | 1.33871 | 0.59062E-04 | 2364 | 1.34405 | 0.59062E-04 | 2464 | 1.34471 | 0.59062E-04 |
| 2266 | 1.33784 | 0.59062E-04 | 2366 | 1.34713 | 0.59062E-04 | 2466 | 1.34340 | 0.59062E-04 |
| 2268 | 1.33705 | 0.59062E-04 | 2368 | 1.35086 | 0.59062E-04 | 2468 | 1.34359 | 0.59062E-04 |
| 2270 | 1.33748 | 0.59062E-04 | 2370 | 1.34555 | 0.59062E-04 | 2470 | 1.34418 | 0.59062E-04 |
| 2272 | 1.33726 | 0.59062E-04 | 2372 | 1.34797 | 0.59062E-04 | 2472 | 1.34445 | 0.59062E-04 |
| 2274 | 1.33682 | 0.59062E-04 | 2374 | 1.34729 | 0.59062E-04 | 2474 | 1.34323 | 0.59062E-04 |
| 2276 | 1.33766 | 0.59062E-04 | 2376 | 1.34958 | 0.59062E-04 | 2476 | 1.34386 | 0.59062E-04 |
| 2278 | 1.34009 | 0.59062E-04 | 2378 | 1.34694 | 0.59062E-04 | 2478 | 1.34477 | 0.59062E-04 |
| 2280 | 1.34139 | 0.59062E-04 | 2380 | 1.34447 | 0.59062E-04 | 2480 | 1.34426 | 0.59062E-04 |
| 2282 | 1.34210 | 0.59062E-04 | 2382 | 1.35002 | 0.59062E-04 | 2482 | 1.34358 | 0.59062E-04 |
| 2284 | 1.34346 | 0.59062E-04 | 2384 | 1.35045 | 0.59062E-04 | 2484 | 1.34386 | 0.59062E-04 |
| 2286 | 1.34574 | 0.59062E-04 | 2386 | 1.34731 | 0.59062E-04 | 2486 | 1.34193 | 0.59062E-04 |
| 2288 | 1.34535 | 0.59062E-04 | 2388 | 1.34612 | 0.59062E-04 | 2488 | 1.34261 | 0.59062E-04 |
| 2290 | 1.34723 | 0.59062E-04 | 2390 | 1.34461 | 0.59062E-04 | 2490 | 1.34285 | 0.59062E-04 |
| 2292 | 1.34700 | 0.59062E-04 | 2392 | 1.34439 | 0.59062E-04 | 2492 | 1.34326 | 0.59062E-04 |
| 2294 | 1.34853 | 0.59062E-04 | 2394 | 1.34256 | 0.59062E-04 | 2494 | 1.34260 | 0.59062E-04 |
| 2296 | 1.35033 | 0.59062E-04 | 2396 | 1.34498 | 0.59062E-04 | 2496 | 1.34134 | 0.59062E-04 |
| 2298 | 1.34770 | 0.59062E-04 | 2398 | 1.34289 | 0.59062E-04 | 2498 | 1.34222 | 0.59062E-04 |

**Table 3. Continued.**

| cm⁻¹ | n | k | cm⁻¹ | n | k | cm⁻¹ | n | k |
|---|---|---|---|---|---|---|---|---|
| 2500 | 1.34262 | 0.59062E-04 | 2600 | 1.34038 | 0.59062E-04 | 2700 | 1.34029 | 0.59062E-04 |
| 2502 | 1.34296 | 0.59062E-04 | 2602 | 1.33921 | 0.59062E-04 | 2702 | 1.33943 | 0.59062E-04 |
| 2504 | 1.34208 | 0.59062E-04 | 2604 | 1.33863 | 0.59062E-04 | 2704 | 1.33975 | 0.59062E-04 |
| 2506 | 1.34163 | 0.59062E-04 | 2606 | 1.33972 | 0.59062E-04 | 2706 | 1.33883 | 0.59062E-04 |
| 2508 | 1.34236 | 0.59062E-04 | 2608 | 1.33812 | 0.59062E-04 | 2708 | 1.33851 | 0.59062E-04 |
| 2510 | 1.34283 | 0.59062E-04 | 2610 | 1.33657 | 0.59062E-04 | 2710 | 1.33917 | 0.59062E-04 |
| 2512 | 1.34214 | 0.59062E-04 | 2612 | 1.33762 | 0.59062E-04 | 2712 | 1.33789 | 0.59062E-04 |
| 2514 | 1.34290 | 0.59062E-04 | 2614 | 1.33858 | 0.59062E-04 | 2714 | 1.33765 | 0.59062E-04 |
| 2516 | 1.34202 | 0.59062E-04 | 2616 | 1.33930 | 0.59062E-04 | 2716 | 1.33842 | 0.59062E-04 |
| 2518 | 1.34201 | 0.59062E-04 | 2618 | 1.33801 | 0.59062E-04 | 2718 | 1.33829 | 0.59062E-04 |
| 2520 | 1.34180 | 0.59062E-04 | 2620 | 1.33787 | 0.59062E-04 | 2720 | 1.33820 | 0.59062E-04 |
| 2522 | 1.34099 | 0.59062E-04 | 2622 | 1.33835 | 0.59062E-04 | 2722 | 1.33749 | 0.59062E-04 |
| 2524 | 1.34206 | 0.59062E-04 | 2624 | 1.33829 | 0.59062E-04 | 2724 | 1.33837 | 0.59062E-04 |
| 2526 | 1.34233 | 0.59062E-04 | 2626 | 1.34047 | 0.59062E-04 | 2726 | 1.33887 | 0.59062E-04 |
| 2528 | 1.34206 | 0.59062E-04 | 2628 | 1.34090 | 0.59062E-04 | 2728 | 1.33837 | 0.59062E-04 |
| 2530 | 1.34147 | 0.59062E-04 | 2630 | 1.34076 | 0.59062E-04 | 2730 | 1.33771 | 0.59062E-04 |
| 2532 | 1.34134 | 0.59062E-04 | 2632 | 1.33983 | 0.59062E-04 | 2732 | 1.33448 | 0.59062E-04 |
| 2534 | 1.34371 | 0.59062E-04 | 2634 | 1.34046 | 0.59062E-04 | 2734 | 1.33679 | 0.59062E-04 |
| 2536 | 1.34102 | 0.59062E-04 | 2636 | 1.34070 | 0.59062E-04 | 2736 | 1.33563 | 0.59062E-04 |
| 2538 | 1.34180 | 0.59062E-04 | 2638 | 1.33835 | 0.59062E-04 | 2738 | 1.33426 | 0.59062E-04 |
| 2540 | 1.33981 | 0.59062E-04 | 2640 | 1.34012 | 0.59062E-04 | 2740 | 1.33389 | 0.59062E-04 |
| 2542 | 1.34116 | 0.59062E-04 | 2642 | 1.33885 | 0.59062E-04 | 2742 | 1.33557 | 0.59062E-04 |
| 2544 | 1.34050 | 0.59062E-04 | 2644 | 1.33873 | 0.59062E-04 | 2744 | 1.33798 | 0.59062E-04 |
| 2546 | 1.34138 | 0.59062E-04 | 2646 | 1.33919 | 0.59062E-04 | 2746 | 1.33900 | 0.59062E-04 |
| 2548 | 1.34337 | 0.59062E-04 | 2648 | 1.33852 | 0.59062E-04 | 2748 | 1.33639 | 0.59062E-04 |
| 2550 | 1.34220 | 0.59062E-04 | 2650 | 1.34016 | 0.59062E-04 | 2750 | 1.33593 | 0.59062E-04 |
| 2552 | 1.34149 | 0.59062E-04 | 2652 | 1.34008 | 0.59062E-04 | 2752 | 1.33575 | 0.59062E-04 |
| 2554 | 1.34034 | 0.59062E-04 | 2654 | 1.33955 | 0.59062E-04 | 2754 | 1.33617 | 0.59062E-04 |
| 2556 | 1.34016 | 0.59062E-04 | 2656 | 1.33873 | 0.59062E-04 | 2756 | 1.33559 | 0.59062E-04 |
| 2558 | 1.34080 | 0.59062E-04 | 2658 | 1.33971 | 0.59062E-04 | 2758 | 1.33488 | 0.59062E-04 |
| 2560 | 1.34149 | 0.59062E-04 | 2660 | 1.34052 | 0.59062E-04 | 2760 | 1.33466 | 0.59062E-04 |
| 2562 | 1.34189 | 0.59062E-04 | 2662 | 1.33972 | 0.59062E-04 | 2762 | 1.33474 | 0.59062E-04 |
| 2564 | 1.34216 | 0.59062E-04 | 2664 | 1.33929 | 0.59062E-04 | 2764 | 1.33574 | 0.59062E-04 |
| 2566 | 1.34247 | 0.59062E-04 | 2666 | 1.33888 | 0.59062E-04 | 2766 | 1.33474 | 0.59062E-04 |
| 2568 | 1.34298 | 0.59062E-04 | 2668 | 1.33936 | 0.59062E-04 | 2768 | 1.33594 | 0.59062E-04 |
| 2570 | 1.34166 | 0.59062E-04 | 2670 | 1.33786 | 0.59062E-04 | 2770 | 1.33395 | 0.59062E-04 |
| 2572 | 1.33993 | 0.59062E-04 | 2672 | 1.33761 | 0.59062E-04 | 2772 | 1.33533 | 0.59062E-04 |
| 2574 | 1.33881 | 0.59062E-04 | 2674 | 1.33874 | 0.59062E-04 | 2774 | 1.33420 | 0.59062E-04 |
| 2576 | 1.33981 | 0.59062E-04 | 2676 | 1.33771 | 0.59062E-04 | 2776 | 1.33327 | 0.59062E-04 |
| 2578 | 1.34046 | 0.59062E-04 | 2678 | 1.33803 | 0.59062E-04 | 2778 | 1.33389 | 0.59062E-04 |
| 2580 | 1.34069 | 0.59062E-04 | 2680 | 1.33889 | 0.59062E-04 | 2780 | 1.33422 | 0.59062E-04 |
| 2582 | 1.33959 | 0.59062E-04 | 2682 | 1.33768 | 0.59062E-04 | 2782 | 1.33643 | 0.59062E-04 |
| 2584 | 1.33990 | 0.59062E-04 | 2684 | 1.33722 | 0.59062E-04 | 2784 | 1.33566 | 0.59062E-04 |
| 2586 | 1.33984 | 0.59062E-04 | 2686 | 1.33758 | 0.59062E-04 | 2786 | 1.33694 | 0.59062E-04 |
| 2588 | 1.33939 | 0.59062E-04 | 2688 | 1.33718 | 0.59062E-04 | 2788 | 1.33763 | 0.59062E-04 |
| 2590 | 1.33828 | 0.59062E-04 | 2690 | 1.33832 | 0.59062E-04 | 2790 | 1.33611 | 0.59062E-04 |
| 2592 | 1.33939 | 0.59062E-04 | 2692 | 1.33850 | 0.59062E-04 | 2792 | 1.33410 | 0.59062E-04 |
| 2594 | 1.34077 | 0.59062E-04 | 2694 | 1.33883 | 0.59062E-04 | 2794 | 1.33527 | 0.59062E-04 |
| 2596 | 1.34020 | 0.59062E-04 | 2696 | 1.33757 | 0.59062E-04 | 2796 | 1.33739 | 0.59062E-04 |
| 2598 | 1.33918 | 0.59062E-04 | 2698 | 1.33960 | 0.59062E-04 | 2798 | 1.33611 | 0.59062E-04 |

**Table 3. Continued.**

| cm⁻¹ | n | k | cm⁻¹ | n | k | cm⁻¹ | n | k |
|---|---|---|---|---|---|---|---|---|
| 2800 | 1.33342 | 0.59062E-04 | 2900 | 1.31012 | 0.19222E-01 | 3000 | 1.27740 | 0.45214E-02 |
| 2802 | 1.33134 | 0.59062E-04 | 2902 | 1.30706 | 0.19025E-01 | 3002 | 1.27523 | 0.35167E-02 |
| 2804 | 1.32633 | 0.59062E-04 | 2904 | 1.30613 | 0.18903E-01 | 3004 | 1.27809 | 0.27600E-02 |
| 2806 | 1.32054 | 0.59062E-04 | 2906 | 1.30842 | 0.18682E-01 | 3006 | 1.27785 | 0.19091E-02 |
| 2808 | 1.31472 | 0.59062E-04 | 2908 | 1.30626 | 0.18702E-01 | 3008 | 1.27767 | 0.13189E-02 |
| 2810 | 1.31277 | 0.71660E-03 | 2910 | 1.30725 | 0.18620E-01 | 3010 | 1.27745 | 0.35440E-03 |
| 2812 | 1.31293 | 0.15717E-02 | 2912 | 1.30651 | 0.18361E-01 | 3012 | 1.28112 | 0.53585E-04 |
| 2814 | 1.31288 | 0.17012E-02 | 2914 | 1.30554 | 0.18276E-01 | 3014 | 1.28375 | 0.59062E-04 |
| 2816 | 1.31101 | 0.15220E-02 | 2916 | 1.30412 | 0.17826E-01 | 3016 | 1.28591 | 0.59062E-04 |
| 2818 | 1.30849 | 0.10868E-02 | 2918 | 1.30762 | 0.17958E-01 | 3018 | 1.28683 | 0.59062E-04 |
| 2820 | 1.30958 | 0.92893E-03 | 2920 | 1.30538 | 0.17517E-01 | 3020 | 1.28812 | 0.59062E-04 |
| 2822 | 1.31151 | 0.97779E-03 | 2922 | 1.30376 | 0.17672E-01 | 3022 | 1.29149 | 0.59062E-04 |
| 2824 | 1.31136 | 0.11585E-02 | 2924 | 1.30573 | 0.17733E-01 | 3024 | 1.29526 | 0.59062E-04 |
| 2826 | 1.31084 | 0.13853E-02 | 2926 | 1.30509 | 0.18030E-01 | 3026 | 1.29762 | 0.59062E-04 |
| 2828 | 1.31183 | 0.20250E-02 | 2928 | 1.30488 | 0.18376E-01 | 3028 | 1.29616 | 0.59062E-04 |
| 2830 | 1.31177 | 0.24301E-02 | 2930 | 1.30572 | 0.18880E-01 | 3030 | 1.29960 | 0.59062E-04 |
| 2832 | 1.31336 | 0.25517E-02 | 2932 | 1.30627 | 0.19334E-01 | 3032 | 1.30065 | 0.59062E-04 |
| 2834 | 1.31235 | 0.25487E-02 | 2934 | 1.30441 | 0.19997E-01 | 3034 | 1.30130 | 0.59062E-04 |
| 2836 | 1.31102 | 0.26291E-02 | 2936 | 1.30626 | 0.20958E-01 | 3036 | 1.30082 | 0.59062E-04 |
| 2838 | 1.31105 | 0.23069E-02 | 2938 | 1.30403 | 0.21474E-01 | 3038 | 1.30323 | 0.59062E-04 |
| 2840 | 1.31044 | 0.20488E-02 | 2940 | 1.30469 | 0.21497E-01 | 3040 | 1.30169 | 0.59062E-04 |
| 2842 | 1.31180 | 0.27495E-02 | 2942 | 1.30440 | 0.21201E-01 | 3042 | 1.30483 | 0.59062E-04 |
| 2844 | 1.31254 | 0.32795E-02 | 2944 | 1.30219 | 0.20653E-01 | 3044 | 1.30327 | 0.59062E-04 |
| 2846 | 1.31275 | 0.36617E-02 | 2946 | 1.30189 | 0.20486E-01 | 3046 | 1.30105 | 0.59062E-04 |
| 2848 | 1.31308 | 0.39500E-02 | 2948 | 1.30230 | 0.20524E-01 | 3048 | 1.30314 | 0.59062E-04 |
| 2850 | 1.31620 | 0.52143E-02 | 2950 | 1.30164 | 0.20290E-01 | 3050 | 1.29947 | 0.59062E-04 |
| 2852 | 1.31516 | 0.62062E-02 | 2952 | 1.30113 | 0.20377E-01 | 3052 | 1.29752 | 0.59062E-04 |
| 2854 | 1.31627 | 0.71744E-02 | 2954 | 1.30149 | 0.20267E-01 | 3054 | 1.29557 | 0.59062E-04 |
| 2856 | 1.31878 | 0.88322E-02 | 2956 | 1.29956 | 0.19870E-01 | 3056 | 1.29943 | 0.59062E-04 |
| 2858 | 1.32018 | 0.10225E-01 | 2958 | 1.30075 | 0.19530E-01 | 3058 | 1.29538 | 0.59062E-04 |
| 2860 | 1.32087 | 0.11245E-01 | 2960 | 1.29748 | 0.19105E-01 | 3060 | 1.29277 | 0.59062E-04 |
| 2862 | 1.32157 | 0.12965E-01 | 2962 | 1.29859 | 0.19169E-01 | 3062 | 1.29210 | 0.59062E-04 |
| 2864 | 1.32203 | 0.14177E-01 | 2964 | 1.29876 | 0.19171E-01 | 3064 | 1.29136 | 0.59062E-04 |
| 2866 | 1.32191 | 0.15202E-01 | 2966 | 1.29845 | 0.19867E-01 | 3066 | 1.28839 | 0.59062E-04 |
| 2868 | 1.32340 | 0.17423E-01 | 2968 | 1.29643 | 0.20312E-01 | 3068 | 1.28829 | 0.59062E-04 |
| 2870 | 1.32365 | 0.18799E-01 | 2970 | 1.29519 | 0.21131E-01 | 3070 | 1.28536 | 0.59062E-04 |
| 2872 | 1.32274 | 0.19924E-01 | 2972 | 1.29518 | 0.22012E-01 | 3072 | 1.28431 | 0.59062E-04 |
| 2874 | 1.32278 | 0.21217E-01 | 2974 | 1.29762 | 0.22201E-01 | 3074 | 1.28421 | 0.59062E-04 |
| 2876 | 1.32170 | 0.21844E-01 | 2976 | 1.29260 | 0.22064E-01 | 3076 | 1.27959 | 0.59062E-04 |
| 2878 | 1.32157 | 0.21880E-01 | 2978 | 1.29386 | 0.21956E-01 | 3078 | 1.28003 | 0.59062E-04 |
| 2880 | 1.31778 | 0.21338E-01 | 2980 | 1.28999 | 0.20836E-01 | 3080 | 1.27855 | 0.52208E-03 |
| 2882 | 1.31828 | 0.21385E-01 | 2982 | 1.28823 | 0.19223E-01 | 3082 | 1.28049 | 0.48074E-03 |
| 2884 | 1.31535 | 0.20803E-01 | 2984 | 1.28766 | 0.18135E-01 | 3084 | 1.27922 | 0.77326E-03 |
| 2886 | 1.31440 | 0.20916E-01 | 2986 | 1.28614 | 0.16376E-01 | 3086 | 1.27688 | 0.11563E-02 |
| 2888 | 1.31755 | 0.20905E-01 | 2988 | 1.28204 | 0.14445E-01 | 3088 | 1.27562 | 0.70129E-03 |
| 2890 | 1.31496 | 0.20757E-01 | 2990 | 1.28268 | 0.12616E-01 | 3090 | 1.27716 | 0.96152E-03 |
| 2892 | 1.31252 | 0.20739E-01 | 2992 | 1.28230 | 0.10764E-01 | 3092 | 1.27543 | 0.14783E-02 |
| 2894 | 1.31051 | 0.20097E-01 | 2994 | 1.27673 | 0.88366E-02 | 3094 | 1.27434 | 0.12424E-02 |
| 2896 | 1.30955 | 0.19815E-01 | 2996 | 1.28012 | 0.72791E-02 | 3096 | 1.27382 | 0.19041E-02 |
| 2898 | 1.30927 | 0.19823E-01 | 2998 | 1.27818 | 0.61460E-02 | 3098 | 1.27275 | 0.19960E-02 |

## Table 3. Continued.

| $cm^{-1}$ | n | k | $cm^{-1}$ | n | k | $cm^{-1}$ | n | k |
|---|---|---|---|---|---|---|---|---|
| 3100 | 1.27559 | 0.23827E-02 | 3200 | 1.22027 | 0.17474E-01 | 3300 | 1.18606 | 0.22533E-01 |
| 3102 | 1.27227 | 0.21272E-02 | 3202 | 1.21843 | 0.17851E-01 | 3302 | 1.18829 | 0.22427E-01 |
| 3104 | 1.27204 | 0.28559E-02 | 3204 | 1.21927 | 0.17679E-01 | 3304 | 1.18982 | 0.22355E-01 |
| 3106 | 1.27170 | 0.30388E-02 | 3206 | 1.21860 | 0.17629E-01 | 3306 | 1.18678 | 0.22586E-01 |
| 3108 | 1.27303 | 0.33457E-02 | 3208 | 1.21734 | 0.18430E-01 | 3308 | 1.19187 | 0.22364E-01 |
| 3110 | 1.27055 | 0.35423E-02 | 3210 | 1.21191 | 0.18805E-01 | 3310 | 1.19414 | 0.22038E-01 |
| 3112 | 1.26898 | 0.39991E-02 | 3212 | 1.21361 | 0.18716E-01 | 3312 | 1.19234 | 0.22271E-01 |
| 3114 | 1.26817 | 0.45215E-02 | 3214 | 1.21536 | 0.19425E-01 | 3314 | 1.19250 | 0.21869E-01 |
| 3116 | 1.26816 | 0.47189E-02 | 3216 | 1.20819 | 0.19416E-01 | 3316 | 1.19165 | 0.21917E-01 |
| 3118 | 1.27033 | 0.49994E-02 | 3218 | 1.20985 | 0.19397E-01 | 3318 | 1.18955 | 0.21483E-01 |
| 3120 | 1.26713 | 0.56399E-02 | 3220 | 1.20892 | 0.19699E-01 | 3320 | 1.19234 | 0.21390E-01 |
| 3122 | 1.26488 | 0.59078E-02 | 3222 | 1.21000 | 0.20060E-01 | 3322 | 1.19521 | 0.22057E-01 |
| 3124 | 1.26389 | 0.60399E-02 | 3224 | 1.20691 | 0.20732E-01 | 3324 | 1.19194 | 0.21736E-01 |
| 3126 | 1.26437 | 0.66651E-02 | 3226 | 1.20306 | 0.20749E-01 | 3326 | 1.19318 | 0.21967E-01 |
| 3128 | 1.26637 | 0.70305E-02 | 3228 | 1.20222 | 0.20724E-01 | 3328 | 1.19386 | 0.21761E-01 |
| 3130 | 1.26231 | 0.68583E-02 | 3230 | 1.20247 | 0.21085E-01 | 3330 | 1.19519 | 0.21592E-01 |
| 3132 | 1.26050 | 0.71590E-02 | 3232 | 1.19867 | 0.20960E-01 | 3332 | 1.19291 | 0.21844E-01 |
| 3134 | 1.26363 | 0.75498E-02 | 3234 | 1.20557 | 0.21050E-01 | 3334 | 1.19465 | 0.22177E-01 |
| 3136 | 1.26139 | 0.79122E-02 | 3236 | 1.20128 | 0.21630E-01 | 3336 | 1.19431 | 0.21946E-01 |
| 3138 | 1.26253 | 0.82478E-02 | 3238 | 1.19699 | 0.21583E-01 | 3338 | 1.19307 | 0.21661E-01 |
| 3140 | 1.26000 | 0.86075E-02 | 3240 | 1.19397 | 0.21720E-01 | 3340 | 1.19099 | 0.21966E-01 |
| 3142 | 1.25828 | 0.91599E-02 | 3242 | 1.19361 | 0.22211E-01 | 3342 | 1.19322 | 0.22304E-01 |
| 3144 | 1.25533 | 0.90573E-02 | 3244 | 1.19392 | 0.22192E-01 | 3344 | 1.19460 | 0.21964E-01 |
| 3146 | 1.25481 | 0.94481E-02 | 3246 | 1.19340 | 0.22604E-01 | 3346 | 1.19331 | 0.21843E-01 |
| 3148 | 1.25265 | 0.98110E-02 | 3248 | 1.18694 | 0.22804E-01 | 3348 | 1.19236 | 0.21476E-01 |
| 3150 | 1.25183 | 0.10024E-01 | 3250 | 1.18487 | 0.22460E-01 | 3350 | 1.19594 | 0.21740E-01 |
| 3152 | 1.25275 | 0.10511E-01 | 3252 | 1.18825 | 0.22935E-01 | 3352 | 1.19369 | 0.21965E-01 |
| 3154 | 1.25010 | 0.10829E-01 | 3254 | 1.18640 | 0.22504E-01 | 3354 | 1.19401 | 0.22172E-01 |
| 3156 | 1.24821 | 0.10709E-01 | 3256 | 1.18657 | 0.22533E-01 | 3356 | 1.19352 | 0.21983E-01 |
| 3158 | 1.25105 | 0.11172E-01 | 3258 | 1.18275 | 0.22933E-01 | 3358 | 1.19654 | 0.22124E-01 |
| 3160 | 1.24777 | 0.11629E-01 | 3260 | 1.18683 | 0.22743E-01 | 3360 | 1.19584 | 0.22601E-01 |
| 3162 | 1.24650 | 0.12216E-01 | 3262 | 1.18510 | 0.22733E-01 | 3362 | 1.19475 | 0.22451E-01 |
| 3164 | 1.24393 | 0.12020E-01 | 3264 | 1.18297 | 0.23076E-01 | 3364 | 1.19341 | 0.22590E-01 |
| 3166 | 1.24191 | 0.12790E-01 | 3266 | 1.18184 | 0.22848E-01 | 3366 | 1.19285 | 0.22645E-01 |
| 3168 | 1.24023 | 0.13025E-01 | 3268 | 1.17980 | 0.23030E-01 | 3368 | 1.19557 | 0.22570E-01 |
| 3170 | 1.24125 | 0.13419E-01 | 3270 | 1.17923 | 0.23672E-01 | 3370 | 1.20108 | 0.22627E-01 |
| 3172 | 1.23973 | 0.13623E-01 | 3272 | 1.18216 | 0.23605E-01 | 3372 | 1.19946 | 0.22938E-01 |
| 3174 | 1.24058 | 0.13793E-01 | 3274 | 1.17660 | 0.23432E-01 | 3374 | 1.19888 | 0.22648E-01 |
| 3176 | 1.23544 | 0.14208E-01 | 3276 | 1.17751 | 0.23030E-01 | 3376 | 1.19660 | 0.22495E-01 |
| 3178 | 1.23958 | 0.14446E-01 | 3278 | 1.18166 | 0.23157E-01 | 3378 | 1.20134 | 0.22650E-01 |
| 3180 | 1.23593 | 0.14511E-01 | 3280 | 1.18211 | 0.22701E-01 | 3380 | 1.19768 | 0.23061E-01 |
| 3182 | 1.23441 | 0.15071E-01 | 3282 | 1.18143 | 0.22482E-01 | 3382 | 1.19968 | 0.22856E-01 |
| 3184 | 1.23142 | 0.15345E-01 | 3284 | 1.17853 | 0.22773E-01 | 3384 | 1.20139 | 0.23075E-01 |
| 3186 | 1.23277 | 0.15631E-01 | 3286 | 1.18802 | 0.22842E-01 | 3386 | 1.19689 | 0.22906E-01 |
| 3188 | 1.22839 | 0.15915E-01 | 3288 | 1.18613 | 0.22335E-01 | 3388 | 1.19621 | 0.22442E-01 |
| 3190 | 1.22664 | 0.16475E-01 | 3290 | 1.18728 | 0.22186E-01 | 3390 | 1.19913 | 0.22926E-01 |
| 3192 | 1.22765 | 0.16640E-01 | 3292 | 1.18876 | 0.22412E-01 | 3392 | 1.20329 | 0.23041E-01 |
| 3194 | 1.22818 | 0.16492E-01 | 3294 | 1.18390 | 0.22491E-01 | 3394 | 1.19893 | 0.22348E-01 |
| 3196 | 1.22424 | 0.16617E-01 | 3296 | 1.18383 | 0.22713E-01 | 3396 | 1.19807 | 0.22773E-01 |
| 3198 | 1.22049 | 0.16746E-01 | 3298 | 1.18328 | 0.22049E-01 | 3398 | 1.20161 | 0.22541E-01 |

**Table 3. Continued.**

| $cm^{-1}$ | n | k | $cm^{-1}$ | n | k | $cm^{-1}$ | n | k |
|---|---|---|---|---|---|---|---|---|
| 3400 | 1.19899 | 0.22508E-01 | 3500 | 1.25079 | 0.17997E-01 | 3600 | 1.28493 | 0.46670E-02 |
| 3402 | 1.20208 | 0.23083E-01 | 3502 | 1.25315 | 0.17813E-01 | 3602 | 1.28286 | 0.38758E-02 |
| 3404 | 1.20366 | 0.22882E-01 | 3504 | 1.25235 | 0.17409E-01 | 3604 | 1.28482 | 0.38617E-02 |
| 3406 | 1.20508 | 0.22428E-01 | 3506 | 1.25025 | 0.18073E-01 | 3606 | 1.28333 | 0.31952E-02 |
| 3408 | 1.20801 | 0.22881E-01 | 3508 | 1.25279 | 0.17991E-01 | 3608 | 1.28579 | 0.27042E-02 |
| 3410 | 1.20567 | 0.22685E-01 | 3510 | 1.25421 | 0.17656E-01 | 3610 | 1.28692 | 0.20940E-02 |
| 3412 | 1.21238 | 0.22492E-01 | 3512 | 1.25418 | 0.17423E-01 | 3612 | 1.28807 | 0.20589E-02 |
| 3414 | 1.20947 | 0.22478E-01 | 3514 | 1.25590 | 0.17218E-01 | 3614 | 1.28834 | 0.15455E-02 |
| 3416 | 1.20983 | 0.22057E-01 | 3516 | 1.25842 | 0.17055E-01 | 3616 | 1.28426 | 0.12685E-02 |
| 3418 | 1.21405 | 0.22096E-01 | 3518 | 1.26037 | 0.16702E-01 | 3618 | 1.28423 | 0.94304E-03 |
| 3420 | 1.21357 | 0.21605E-01 | 3520 | 1.25907 | 0.16670E-01 | 3620 | 1.28072 | 0.71294E-04 |
| 3422 | 1.21202 | 0.22216E-01 | 3522 | 1.25881 | 0.15955E-01 | 3622 | 1.28773 | 0.12679E-03 |
| 3424 | 1.21060 | 0.21653E-01 | 3524 | 1.26580 | 0.15993E-01 | 3624 | 1.28648 | 0.91285E-04 |
| 3426 | 1.21537 | 0.21754E-01 | 3526 | 1.26526 | 0.16248E-01 | 3626 | 1.29202 | 0.59062E-04 |
| 3428 | 1.21325 | 0.21948E-01 | 3528 | 1.26267 | 0.15506E-01 | 3628 | 1.29148 | 0.59062E-04 |
| 3430 | 1.21680 | 0.21488E-01 | 3530 | 1.26175 | 0.14807E-01 | 3630 | 1.29285 | 0.59062E-04 |
| 3432 | 1.21700 | 0.21687E-01 | 3532 | 1.26613 | 0.14680E-01 | 3632 | 1.29680 | 0.59062E-04 |
| 3434 | 1.21820 | 0.21690E-01 | 3534 | 1.26634 | 0.14354E-01 | 3634 | 1.29394 | 0.59062E-04 |
| 3436 | 1.22224 | 0.21698E-01 | 3536 | 1.27065 | 0.14621E-01 | 3636 | 1.29521 | 0.59062E-04 |
| 3438 | 1.22205 | 0.21772E-01 | 3538 | 1.27374 | 0.13954E-01 | 3638 | 1.29230 | 0.59062E-04 |
| 3440 | 1.22247 | 0.21525E-01 | 3540 | 1.26846 | 0.13905E-01 | 3640 | 1.29194 | 0.59062E-04 |
| 3442 | 1.22512 | 0.21221E-01 | 3542 | 1.27410 | 0.13535E-01 | 3642 | 1.29137 | 0.59062E-04 |
| 3444 | 1.22085 | 0.21300E-01 | 3544 | 1.27092 | 0.12942E-01 | 3644 | 1.29576 | 0.59062E-04 |
| 3446 | 1.22094 | 0.21080E-01 | 3546 | 1.26762 | 0.12969E-01 | 3646 | 1.29865 | 0.59062E-04 |
| 3448 | 1.22075 | 0.20469E-01 | 3548 | 1.27092 | 0.12628E-01 | 3648 | 1.30497 | 0.59062E-04 |
| 3450 | 1.22920 | 0.20587E-01 | 3550 | 1.27384 | 0.12766E-01 | 3650 | 1.29426 | 0.59062E-04 |
| 3452 | 1.22839 | 0.20755E-01 | 3552 | 1.27553 | 0.12592E-01 | 3652 | 1.29911 | 0.59062E-04 |
| 3454 | 1.22710 | 0.20257E-01 | 3554 | 1.27418 | 0.12013E-01 | 3654 | 1.29951 | 0.59062E-04 |
| 3456 | 1.23108 | 0.19964E-01 | 3556 | 1.27290 | 0.11816E-01 | 3656 | 1.29663 | 0.59062E-04 |
| 3458 | 1.23174 | 0.19808E-01 | 3558 | 1.27649 | 0.11972E-01 | 3658 | 1.29965 | 0.59062E-04 |
| 3460 | 1.23549 | 0.19586E-01 | 3560 | 1.27509 | 0.11477E-01 | 3660 | 1.30199 | 0.59062E-04 |
| 3462 | 1.23594 | 0.19163E-01 | 3562 | 1.27790 | 0.10746E-01 | 3662 | 1.30023 | 0.59062E-04 |
| 3464 | 1.23700 | 0.19370E-01 | 3564 | 1.27670 | 0.10507E-01 | 3664 | 1.30139 | 0.59062E-04 |
| 3466 | 1.24046 | 0.19250E-01 | 3566 | 1.27514 | 0.10866E-01 | 3666 | 1.30182 | 0.59062E-04 |
| 3468 | 1.24384 | 0.19502E-01 | 3568 | 1.27766 | 0.93350E-02 | 3668 | 1.30027 | 0.59062E-04 |
| 3470 | 1.24321 | 0.19246E-01 | 3570 | 1.28332 | 0.89001E-02 | 3670 | 1.29802 | 0.59062E-04 |
| 3472 | 1.24030 | 0.19393E-01 | 3572 | 1.28054 | 0.93863E-02 | 3672 | 1.30539 | 0.59062E-04 |
| 3474 | 1.24079 | 0.18722E-01 | 3574 | 1.27998 | 0.96648E-02 | 3674 | 1.30415 | 0.59062E-04 |
| 3476 | 1.24423 | 0.19169E-01 | 3576 | 1.28283 | 0.91025E-02 | 3676 | 1.30066 | 0.59062E-04 |
| 3478 | 1.24216 | 0.19270E-01 | 3578 | 1.28107 | 0.88815E-02 | 3678 | 1.30315 | 0.59062E-04 |
| 3480 | 1.24149 | 0.18953E-01 | 3580 | 1.28275 | 0.83782E-02 | 3680 | 1.30652 | 0.59062E-04 |
| 3482 | 1.24055 | 0.19209E-01 | 3582 | 1.28412 | 0.82373E-02 | 3682 | 1.30701 | 0.59062E-04 |
| 3484 | 1.24320 | 0.19073E-01 | 3584 | 1.28224 | 0.84157E-02 | 3684 | 1.30553 | 0.59062E-04 |
| 3486 | 1.24622 | 0.18813E-01 | 3586 | 1.28217 | 0.80787E-02 | 3686 | 1.30128 | 0.59062E-04 |
| 3488 | 1.24438 | 0.19595E-01 | 3588 | 1.28431 | 0.69424E-02 | 3688 | 1.29704 | 0.59062E-04 |
| 3490 | 1.24589 | 0.18676E-01 | 3590 | 1.28722 | 0.63807E-02 | 3690 | 1.29578 | 0.59062E-04 |
| 3492 | 1.24715 | 0.18666E-01 | 3592 | 1.28439 | 0.62407E-02 | 3692 | 1.29835 | 0.59062E-04 |
| 3494 | 1.24996 | 0.18858E-01 | 3594 | 1.28187 | 0.59558E-02 | 3694 | 1.30215 | 0.59062E-04 |
| 3496 | 1.24799 | 0.18910E-01 | 3596 | 1.28021 | 0.52102E-02 | 3696 | 1.30225 | 0.59062E-04 |
| 3498 | 1.24871 | 0.18282E-01 | 3598 | 1.28378 | 0.55228E-02 | 3698 | 1.29841 | 0.59062E-04 |

**Table 3. Concluded.**

| cm⁻¹ | n | k | cm⁻¹ | n | k | cm⁻¹ | n | k |
|---|---|---|---|---|---|---|---|---|
| 3700 | 1.29783 | 0.59062E-04 | 3800 | 1.30636 | 0.59062E-04 | 3900 | 1.30770 | 0.59062E-04 |
| 3702 | 1.30050 | 0.59062E-04 | 3802 | 1.30355 | 0.59062E-04 | 3902 | 1.30773 | 0.59062E-04 |
| 3704 | 1.30274 | 0.59062E-04 | 3804 | 1.30955 | 0.59062E-04 | 3904 | 1.30939 | 0.59062E-04 |
| 3706 | 1.30422 | 0.59062E-04 | 3806 | 1.30859 | 0.59062E-04 | 3906 | 1.31154 | 0.59062E-04 |
| 3708 | 1.30769 | 0.59062E-04 | 3808 | 1.30578 | 0.59062E-04 | 3908 | 1.31078 | 0.59062E-04 |
| 3710 | 1.30444 | 0.59062E-04 | 3810 | 1.30808 | 0.59062E-04 | 3910 | 1.30815 | 0.59062E-04 |
| 3712 | 1.29596 | 0.59062E-04 | 3812 | 1.30798 | 0.59062E-04 | 3912 | 1.30894 | 0.59062E-04 |
| 3714 | 1.30561 | 0.59062E-04 | 3814 | 1.30527 | 0.59062E-04 | 3914 | 1.30744 | 0.59062E-04 |
| 3716 | 1.30665 | 0.59062E-04 | 3816 | 1.30014 | 0.59062E-04 | 3916 | 1.30802 | 0.59062E-04 |
| 3718 | 1.29977 | 0.59062E-04 | 3818 | 1.30529 | 0.59062E-04 | 3918 | 1.30639 | 0.59062E-04 |
| 3720 | 1.30115 | 0.59062E-04 | 3820 | 1.30519 | 0.59062E-04 | 3920 | 1.31072 | 0.59062E-04 |
| 3722 | 1.30650 | 0.59062E-04 | 3822 | 1.30468 | 0.59062E-04 | 3922 | 1.30792 | 0.59062E-04 |
| 3724 | 1.30443 | 0.59062E-04 | 3824 | 1.30957 | 0.59062E-04 | 3924 | 1.31021 | 0.59062E-04 |
| 3726 | 1.30584 | 0.59062E-04 | 3826 | 1.30893 | 0.59062E-04 | 3926 | 1.30998 | 0.59062E-04 |
| 3728 | 1.30711 | 0.59062E-04 | 3828 | 1.30945 | 0.59062E-04 | 3928 | 1.31036 | 0.59062E-04 |
| 3730 | 1.30336 | 0.59062E-04 | 3830 | 1.30795 | 0.59062E-04 | 3930 | 1.31054 | 0.59062E-04 |
| 3732 | 1.30130 | 0.59062E-04 | 3832 | 1.30666 | 0.59062E-04 | 3932 | 1.31199 | 0.59062E-04 |
| 3734 | 1.29973 | 0.59062E-04 | 3834 | 1.30699 | 0.59062E-04 | 3934 | 1.31364 | 0.59062E-04 |
| 3736 | 1.30788 | 0.59062E-04 | 3836 | 1.30830 | 0.59062E-04 | 3936 | 1.31188 | 0.59062E-04 |
| 3738 | 1.30743 | 0.59062E-04 | 3838 | 1.30478 | 0.59062E-04 | 3938 | 1.30999 | 0.59062E-04 |
| 3740 | 1.30643 | 0.59062E-04 | 3840 | 1.30878 | 0.59062E-04 | 3940 | 1.31079 | 0.59062E-04 |
| 3742 | 1.30900 | 0.59062E-04 | 3842 | 1.31173 | 0.59062E-04 | 3942 | 1.31106 | 0.59062E-04 |
| 3744 | 1.30527 | 0.59062E-04 | 3844 | 1.30406 | 0.59062E-04 | 3944 | 1.30980 | 0.59062E-04 |
| 3746 | 1.30858 | 0.59062E-04 | 3846 | 1.30644 | 0.59062E-04 | 3946 | 1.30981 | 0.59062E-04 |
| 3748 | 1.30560 | 0.59062E-04 | 3848 | 1.30795 | 0.59062E-04 | 3948 | 1.30890 | 0.59062E-04 |
| 3750 | 1.29511 | 0.59062E-04 | 3850 | 1.30740 | 0.59062E-04 | 3950 | 1.30960 | 0.59062E-04 |
| 3752 | 1.28688 | 0.59062E-04 | 3852 | 1.31568 | 0.59062E-04 | 3952 | 1.31042 | 0.59062E-04 |
| 3754 | 1.30595 | 0.59062E-04 | 3854 | 1.31303 | 0.59062E-04 | 3954 | 1.31259 | 0.59062E-04 |
| 3756 | 1.30547 | 0.59062E-04 | 3856 | 1.30610 | 0.59062E-04 | 3956 | 1.31152 | 0.59062E-04 |
| 3758 | 1.30790 | 0.59062E-04 | 3858 | 1.30997 | 0.59062E-04 | 3958 | 1.31025 | 0.59062E-04 |
| 3760 | 1.30722 | 0.59062E-04 | 3860 | 1.30843 | 0.59062E-04 | 3960 | 1.30876 | 0.59062E-04 |
| 3762 | 1.30729 | 0.59062E-04 | 3862 | 1.30776 | 0.59062E-04 | 3962 | 1.31076 | 0.59062E-04 |
| 3764 | 1.30626 | 0.59062E-04 | 3864 | 1.30362 | 0.59062E-04 | 3964 | 1.31388 | 0.59062E-04 |
| 3766 | 1.30687 | 0.59062E-04 | 3866 | 1.30537 | 0.59062E-04 | 3966 | 1.31068 | 0.59062E-04 |
| 3768 | 1.30537 | 0.59062E-04 | 3868 | 1.30820 | 0.59062E-04 | 3968 | 1.31205 | 0.59062E-04 |
| 3770 | 1.30420 | 0.59062E-04 | 3870 | 1.31124 | 0.59062E-04 | 3970 | 1.31250 | 0.59062E-04 |
| 3772 | 1.30777 | 0.59062E-04 | 3872 | 1.31411 | 0.59062E-04 | 3972 | 1.31150 | 0.59062E-04 |
| 3774 | 1.30538 | 0.59062E-04 | 3874 | 1.31418 | 0.59062E-04 | 3974 | 1.31068 | 0.59062E-04 |
| 3776 | 1.30348 | 0.59062E-04 | 3876 | 1.31154 | 0.59062E-04 | 3976 | 1.31401 | 0.59062E-04 |
| 3778 | 1.30746 | 0.59062E-04 | 3878 | 1.30849 | 0.59062E-04 | 3978 | 1.31355 | 0.59062E-04 |
| 3780 | 1.30751 | 0.59062E-04 | 3880 | 1.30657 | 0.59062E-04 | 3980 | 1.31251 | 0.59062E-04 |
| 3782 | 1.30738 | 0.59062E-04 | 3882 | 1.30664 | 0.59062E-04 | 3982 | 1.31218 | 0.59062E-04 |
| 3784 | 1.30796 | 0.59062E-04 | 3884 | 1.30808 | 0.59062E-04 | 3984 | 1.31232 | 0.59062E-04 |
| 3786 | 1.30750 | 0.59062E-04 | 3886 | 1.30964 | 0.59062E-04 | 3986 | 1.31164 | 0.59062E-04 |
| 3788 | 1.30706 | 0.59062E-04 | 3888 | 1.31301 | 0.59062E-04 | 3988 | 1.31299 | 0.59062E-04 |
| 3790 | 1.30672 | 0.59062E-04 | 3890 | 1.31246 | 0.59062E-04 | 3990 | 1.31066 | 0.59062E-04 |
| 3792 | 1.30759 | 0.59062E-04 | 3892 | 1.30781 | 0.59062E-04 | 0 | 0.00000 | 0.00000E+00 |
| 3794 | 1.30603 | 0.59062E-04 | 3894 | 1.31094 | 0.59062E-04 | 0 | 0.00000 | 0.00000E+00 |
| 3796 | 1.30679 | 0.59062E-04 | 3896 | 1.30805 | 0.59062E-04 | 0 | 0.00000 | 0.00000E+00 |
| 3798 | 1.30872 | 0.59062E-04 | 3898 | 1.30756 | 0.59062E-04 | 0 | 0.00000 | 0.00000E+00 |